NOVEL SOCIAL IMPACT ASSESSMENT FRAMEWORK

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NOVEL SOCIAL IMPACT ASSESSMENT FRAMEWORK

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SUMMARY

Sustainability assessments provide methodologies to assess the environmental, economic and social impacts of products along their complete lifecycle. Relative to environmental and economic impact assessments, the social impact assessment field is the least developed. This has resulted in a lack of consensus and a fragmented field without standardization. The purpose of this research is to develop a novel social impact assessment (SIA) framework. The scope of the framework is limited to assessing social impacts of products using quantitative and qualitative indicators. The research plan is summarized in three steps: 1) systematic mapping and analysis of the social impact assessment field, 2) novel SIA framework development and 3) evaluation of the novel framework. A systematic mapping of the SIA field is presented, along with the identification of twelve recurring challenges to perform a SIA. The evaluation of the novel framework combines expert and novice user feedback with a case study application. The expert feedback was used to verify the relevance of the identified SIA challenges. Using the novice feedback data, the simplified SIA framework was modified to make it more applicable to capstone design students. The case study application involved the use of the novel SIA framework to describe the potential social impacts of rooftop solar panels in the state of Georgia. The results highlighted the dangers involved for the workers installing the solar panels and the need for regulation and plans to make the solar panels accessible to low-income community members. The feedback and case study learnings were then used to update the SIA framework, which resulted in the finalized version, presented in this thesis. There are four technical

contributions from this work: 1) the identification of a recurring set of challenges to performing SIA, 2) a systematic mapping of academic and non-academic articles, methodologies and case studies of the SIA field, 3) the creation of an indicator database, and 4) the creation of a novel SIA framework. In addition to the technical contributions, there are three expected broader impacts from the use of the novel SIA framework. The first is the development of products with higher positive social impacts, as designers will have more information about the possible social consequences of their design choices. In addition, the use of the framework in a college level course enables students to learn the science of SIAs and how to implement them. Finally, the information obtained from the implementation of the novel SIA framework can be used to inform policy development. Such policy initiatives should aim to protect communities from unintended negative social consequences of products and new technologies.

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NOMENCLATURE

Activity variable	Provides relative importance of process based on a quantitative measure. Examples include number of worker hours in process or relative value added by process [1].
Aggregation	Summing or bringing together of information (e.g., data, indicator results, etc.) from smaller units into a larger unit. (e.g., from inventory indicator to subcategory). In Social Lifecycle Assessment (S-LCA), the aggregation of data may be done at the life cycle inventory or impact assessment phase, and should not be done in a way that leads to any loss of information about the location of the unit processes [2].
Allocation	Partitioning of the input or output flows of a process or a product system between the product system under study and one or more other product systems inside of the system boundaries [3]. It is basically the division of impacts between the product system under study, and one or more product systems with which it interacts [4].
Area of Protection (AOP)	Cluster of category endpoints of recognizable value to society e.g., human health, natural resources, natural environment and man-made environment.
Characterization	Determination and/or calculation of results for subcategory indicators [2].
Classification	Relating of the inventory data to particular stakeholder categories, impact categories and subcategories [2].
Consumers stakeholder group	Individuals or group of individuals with direct contact to the product or service but that are not workers.
Environmental Endpoint	Represents the environmental damages caused to an area of protection (AOP), i.e., the biotic natural environment or human health [2].
Environmental Lifecycle Assessment (E-LCA)	Assessment technique that aims at addressing the environmental aspects and their potential environmental impacts throughout a product’s life cycle.
Functional Unit	Quantified performance of a product for use as a reference unit [3].
Impact Indicator	Quantifiable representation of an impact category [3].
Impact Category	Logical groupings of S-LCA results, related to social issues of interest to stakeholders and decision makers [2].
Normalization	Calculation of the magnitude of category indicator results relative to reference information [3].
Input	Product, material or energy flow that enters a unit process [3].
Life Cycle Costing (LCC)	Assessment of economic factors along the life cycle of the product [5]. It is a compilation and assessment of all costs

	related to a product, over its entire life cycle, from production to use, maintenance and disposal [2].
Life Cycle Inventory (LCI)	Phase of a S-LCA in which data are collected, the systems are modeled, and the life cycle inventory (LCI) results are obtained [2].
Life Cycle Sustainability Assessment (LCSA)	Assesses the sustainability of a product by combining the results of the Life Cycle Costing (LCC), Environmental Life Cycle Assessment (E-LCA) and Social-Life Cycle Assessment (S-LCA) along its complete lifecycle [5].
Local community stakeholder group	Individuals or group of individuals living near the vicinity of where the product or service lifecycle activities take place.
Materiality	The quality of being relevant or significant [6]
Midpoint	Covers an environmental problem that stands between the LCI and the final damage in the AOP [2].
Output	Product, material or energy flow that leaves a unit process [3].
Performance Reference Point (PRP)	Additional information used in characterization models, which may be internationally set thresholds, goals or objectives according to conventions and best practices, etc. [2].
Product Service System (PSS)	A PSS has been defined as a marketable set of products and services capable of jointly fulfilling a user's need [7].
Social Endpoint	A social attribute or aspect identifying an issue giving cause for concern (e.g., well-being of stakeholders). Adapted from ISO 14040 [2,3].
Social Hotspot	Countries, sectors or areas of concern in a supply chain based on their potential social impacts [8]. Social hotspots are unit processes located in a region where a situation occurs that may be considered as a problem, a risk or an opportunity, in function of a social theme of interest. The social theme of interest represents issues that are considered to be threatening social well-being or that may contribute to its further development [2].
Social Hotspot Database	Input-output S-LCA database that provides social risk information based on social theme table and worker hours [8].
Social Impact	Impact that influences the experience of an individual or a community [9]. Social impacts are define as the consequences on stakeholders from activities along the product lifecycle [2].
Social Process	Intervening factor that influences whether a community is likely to experience social impacts [9].
Social Impact Assessment (SIA)	Social impact assessment (SIA) provides a method to assess the social impacts of a single process and/or plant related to a product or service, and it is often used in the context of development projects [10]. Refers to the process of defining, monitoring, and employing measures to demonstrate benefits created for the target beneficiaries and communities through social outcomes and impacts [11]. It is the process of

	identifying the social consequences or impacts that are likely to follow specific policy actions or project development, to assess the significance of these impacts and to identify measures that may help to avoid or minimize adverse effects [2].
Social Lifecycle Assessment (S-LCA)	Social impact assessment technique that aims to assess he social and socio-economic aspects of products and their potential positive and negative impacts along their lifecycle [2].
Society stakeholder group	Refers to normative legal agreements and practices that occur at a higher geographical scale relative to the local community stakeholder group.
Stakeholder	Individual or group that has an interest in or is impacted by any activities or decisions of an organization [12].
Stakeholder Category	Cluster of stakeholders that are expected to have similar interests due to their similar relationship to the investigated product systems [2].
Stakeholder Theory	Theory that identifies and models the stakeholder groups of a corporation, and both describes and recommends methods by which management can give due regard to the interests of those groups [13].
System Boundaries	Set of criteria specifying which unit processes are part of a product system [3].
Systematic Literature Review	A systematic review may be defined as a structured evaluation of the literature with the goal of answering a specific research or application question with a syn- thesis of the best available evidence, generally published to share these results with a wide audience for consideration and implementation [14].
Sustainable Development	Development that attends current society needs without compromising he ability of future generations to meet their own needs [15].
Sustainability Assessment	Appraisal method for supporting decision making and policy in a broad environmental, economic and social context, improving the technical and scientific evaluation [16].
Tri-pillar Sustainability Model	Sustainability is modelled as the following three independent pillars: the environmental, economic and social pillars. This is the basis of the Life Cycle Sustainability Assessment (LCSA) model [5].
Value-chain actors stakeholder group	Individuals or groups of individuals that are involved in the product lifecycle without having direct contact with the product and whose involvement is crucial for the development of the product or service being assessed [2].
Weighting	Converting and possibly aggregating indicator results across impact categories, using numerical factors based on value-choices; data prior to weighting should remain available [3].

Workers stakeholder group	Stakeholder group consisting of individuals or groups of individuals that have direct contact with the product throughout its lifecycle but that are not consumers. [2,6]

CHAPTER 1 INTRODUCTION

The Report of the World Commission on Environment and Development: Our Common Future provides the following definition of sustainability: “Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those in the future” [15]. Sustainability is often represented by the tripartite model, in which it is divided in three interconnected pillars: the economic, environmental and social pillars [17]. By defining sustainability as three separate components, each pillar can be evaluated separately. This model has been criticized because it balances and makes trade-offs among the three pillars, which is not recommended [18].

The concept of sustainability has been extended to product design, which has resulted in the field of sustainable product development. Sustainable product development involves the adoption of lifecycle practices that reduce the negative economic, environmental and social impacts of a product. Among the different methods available for performing social assessments, social impact assessment (SIA) provides a method to assess the social impacts of a single process and/or plant related to a product or service, and it is often used in the context of development projects [10]. A social impact assessment is defined as “a systematic appraisal of impacts on the quality of life of persons and communities whose environment is affected by a proposed policy, plan, program or project” [19].

Relative to the environmental and economic assessment fields, the social impact assessment field is not well studied. One possible explanation is the perception that ecological aspects are more urgent than social aspects, and that there are complex relationships and interdependencies between social and economic issues [20]. Social impact assessments were developed in the 1970s [21] as an extension of environmental impact assessments [2], which resulted in the application of environmental impact approaches to perform the social assessments. This resulted in significant technical challenges, as social impacts tend to be more far reaching than environmental impacts, which are usually more focused in the locations being studied.

Two publications that have contributed to the advancement of the SIA field are the 2009 United Nations Environment Program/Society of Environmental Toxicology and Chemistry (UNEP/SETAC) Guidelines [10] and the 2013 UNEP/SETAC Methodological Sheets [22]. Although the two aforementioned publications have resulted in an increased number of publications related to SIA in recent years [23–26], SIA practitioners still face significant challenges. In contrast to performing environmental and economic assessments, social impacts are not easy to quantify because there are no clear impact pathways established between the inputs and outputs of the product system studied. Some may even say that social impacts are not quantifiable at all. Furthermore, the field has not reached standardization, and there is significant variability in the approaches followed when performing the assessments. This lack of standardization results in the impossibility of achieving agreement even on the most basic matters, making the process of consolidating knowledge difficult.

One approach to address the issue of lack of standardization is to analyze the large collection of results and studies in SIA with the purpose of integrating individual findings, to establish a detailed understanding of the field by means of an evidence synthesis method. Evidence synthesis methods follow a rigorous and transparent process, aiming to reduce reviewer selection and publication bias, and to enable the reader to review all of the decisions made in order to screen the selected articles [27]. A well-regarded evidence synthesis method is the systematic review. A systematic review is defined as "a structured evaluation of the literature with the goal of answering a specific research or application question with a synthesis of the best available evidence." [14]. This method reduces the subjectivity in drawing conclusions [24,28], reveals trends, relationships and gaps in the literature in order to synthesize, organize and evaluate what is known and what is unknown within a particular field [29].

Although a systematic review is a powerful method for performing evidence synthesis, its feasibility to answer openly framed questions such as the ones explored in this thesis, is questionable. Openly framed questions require the inclusion of evidence from heterogeneous sources, which make difficult the resulting synthesis process presented in the systematic reviews [26]. Answering the research questions presented in this thesis involve the collection of information sources that may not allow a quantitative synthesis to answer them. Based upon the nature of this thesis, the author opted for performing a systematic mapping of the social impact assessment field. By means of a systematic mapping, the objective is to determine the state of the knowledge of the social impact assessment field, identify research gaps for future research directions, and to identify a set of fundamental challenges involving the application of social impact assessments. The research question investigated through the systematic mapping is the following: "What are the current methods available to perform social impact assessments, and how have they been implemented?" Details about the systematic mapping procedure are presented in Chapter 4 to ensure process transparency, results replicability and an appropriate update of results if any related data is generated in future studies [14].

A motivation of this thesis is to advance the field by developing a novel SIA methodology. With this in mind, the research plan was developed using the Design Research Method (DRM) [30]. DRM provides a structured framework for developing and evaluating process improvement tools. The DRM method organizes the research plan into four stages: the Research Clarification (RC) Stage, The Descriptive Study I (DS-I) Stage, the Prescriptive Study (PS) Stage and the Descriptive Study II (DS-II) Stage. The DRM method is explained in detail in the Literature Review chapter of this thesis. The research starts by performing a literature review of the SIA field to identify gaps and challenges. A novel framework is then developed to address the identified gaps. Finally, methods and results to evaluate the novel framework are presented.

This thesis is organized based on the research plan. Chapter 2 presents the literature review, along with an in-depth explanation of the Design Research Methodology (DRM). Chapter 3 presents a motivational case study that provided the backbone to formulate the research questions presented in this thesis. Chapter 4 provides the results of the Descriptive Study I stage, where the procedure followed to obtain a detailed understanding of the SIA field is presented along with its learnings. Chapters 5-8 describe the steps for developing the novel SIA framework. Chapter 5 presents the novel SIA framework along with instructions on how it should be implemented. In Chapter 6, expert feedback regarding the SIA framework gathered through online surveys is synthesized and used to enhance the challenges identified. In Chapter 7, feedback from senior undergraduate capstone students gathered through online surveys is analyzed, summarized and used to enhance the framework. Because of the time constraints of the senior capstone course, a simplified version of the framework was provided to the students. In this version, the impact assessment portion of the analysis is not included as the goal is for the students to prepare a social impact assessment plan and to reflect on the expected learnings from the assessment. In Chapter 8, the framework is theory tested by applying it to a case study of rooftop solar panels. The SIA process and use of the novel framework is explained, and the results are presented. Chapter 9 highlights the contributions of the thesis, and Chapter 10 presents recommended future research to advance the SIA field. Chapter 11 discusses the known limitations of the thesis, and Chapter 12 presents overall conclusions for the thesis.

CHAPTER 2 BACKGROUND

2.1 Introduction

Early social impact assessments (SIA) were developed in the 1970's and were created as an extension to environmental impact assessments [2]. The major challenges arising in SIA result from the difficulty of adapting an environmental assessment technique for social impact purposes. In this chapter a brief summary of methods to perform environmental and economic assessments is presented before introducing the topic of SIAs. An in-depth review of the SIA literature is presented in Chapter 4. The chapter then proceeds to introduce the Design Research Methodology (DRM) from Blessing [30]. DRM is used to structure the research plan presented in this thesis to develop a novel SIA framework. It is important for the reader to understand how such a methodology is structured and how it is implemented in this work. Concluding remarks are presented, along with the next steps to be followed in the research study.

2.2 Methods for Performing Environmental Assessments

Although the focus of this dissertation is on social impact assessments, it is important to emphasize the connection and history that exists between social impact assessments and environmental impact assessments. Most of the work regarding social impacts derived from the interest of researchers to complement the environmental impact assessments with a social component. Below, a list of different methods found in the literature to perform environmental impact assessments are presented. In the next chapter, as part of the systematic mapping of the social impact assessment field, an in-depth review of the social impact assessment literature and state of the art is presented. As such, the remainder of this chapter only focuses on environmental impact assessments, to provide the foundation, history and background behind social impact assessments methods.

2.2.1 Environmental Life Cycle Assessment (LCA)

Environmental Life Cycle Assessment, or LCA, is a well-established method to evaluate the potential environmental impact of products and services along their lifecycle. LCA started with energy analysis and has gone through a period of standardization and harmonization of its framework and terminology [31]. The framework has reached a standardized status as expressed in the International Standard ISO 14040 "Environmental management-Life Cycle assessment-Principles and Framework" [32]. The LCA method is a technique for assessing the environmental impacts associated with a product by compiling an inventory of the relevant inputs and outputs of a product system, evaluating the potential environmental impacts associated with those inputs and outputs, and interpreting the results of the inventory analysis and impact assessment phases of the product lifecycle.

The analysis consists of 4 different steps: *1) goal and scope definition, 2) inventory analysis, 3) impact assessment and 4) interpretation of results* [32].

2.2.1.1 Goal and Scope Definition

The goal states the intended application, the reasons for carrying out the LCA and the intended audience. The scope should define clearly the breadth and the level of detail of the LCA, and the functional unit to be used. The functional unit is defined as a measure of the performance of the functional outputs of the product system. The main purpose of the functional unit is to provide a reference for the input and output values. Another important part of goal and scope process is to define the system boundaries. The system boundaries define the physical limits of the processes that will be included in the analysis. There are many factors that will determine the definition of the system boundaries including but not limited to the scope, the assumptions made in the LCA, data and temporal constraints and the intended audience for the results.

2.2.1.2 Inventory Analysis

The next step is to develop the inventory to be used in the analysis. Based on the goal, scope and system boundary definitions, the LCA inventory analysis involves data collection of the inputs and outputs to the system. This information is then used to quantity the amount of resources and environmental impacts caused by the system.

2.2.1.3 Impact Assessment

The next step is the impact assessment calculation, which uses the LCA inventory data to calculate the environmental impact. The method used for the calculation of the impact will vary on the selection of the user as there exists numerous methods to perform environmental impact calculations.

2.2.1.4 Interpretation of Results

The last step of the LCA analysis is to interpret the results from the impact assessment [32]. In this step, the significant issues identified in the LCA are presented. The conclusions of the LCA are presented along with its limitations. The interpretation of the LCA results should be done relative to the goal and scope definitions [3].

2.2.2 Environmental Impact Assessment

The Environmental Impact Assessment (EIA) of projects requires public and private projects that are likely to have significant effects on the environment be made subject to an assessment. EIA has proven to be a great tool for evaluating the environmental risks and opportunities of project proposals and project outcomes [33]. This method involves the following three stages: 1) screening, 2) scoping and 3) preparation of the report. The scoping stage provides the opportunity for developers to ask competent authorities about the extent of information required to make an informed decision about the project and its effects. This step involves the assessment and determination of the amount of information that the authorities will need. The last stage is the preparation of the report, which presents the output of the assessment including the baseline scenario, the different alternatives and the measures to mitigate adverse significant effects from the project [34].

2.2.3 Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment (SEA) is defined as an analytical and participatory approach to strategic decision making that aims to integrate environmental considerations into policy, plans and programs, and evaluate the interlinkages with economic and social considerations [33]. The crucial component of SEA is the understanding that relative to performing environmental impact assessment of individual projects, strategic level interventions at the policy level are more influenced by political factors than by technical criteria. More important is the fact that environmental effects associated with policy decisions are often indirect and happen over a long period of time. SEA allows the integration of environmental aspects, alongside the economic and social aspects at all stages of development cooperation [33,35]. Although the validity and effectiveness of performing an EIA has been proven, its applicability is further downstream in the process. As a response, SEA involves informing decisions at the strategic decision level rather than at the project level. By addressing choices upstream of projects, SEA is able to consider a wider array of development options that are not considered by EIA.

2.2.4 Environmental Footprint or Ecological Footprint

The Ecological Footprint is an account-based system of indicators whose underlying context is the recognition that the Earth has a finite amount of biological resources that support all life upon it. The ecological footprint provides an integrated, multistep approach to tracking the use and overuse of natural resources, and the consequent impacts on ecosystems and biodiversity [36]. The ecological footprint accounting is driven by the following question: How much of the biosphere's regenerative capacity does human activity demand? The accountability is performed based on the sustainability principles taken from Daly [37]: 1) renewable resources must not be consumed faster than they are regenerated and 2) waste must not be created faster than what it is assimilated by natural systems.

Human Harvest and Waste Production

Waste production is quantified in mass per time and translated into global hectares through the following equation:

$$EF_{production} = \frac{P}{Y_w} * EQF \quad (1)$$

where:

- P is the production in tons per year
- Y_w is the world average yield in tons per hectare, per year
- EQF is the equivalence factor

EQF is defined as the ratio of a given land type's average global productivity divided by the average global productivity of the entire productive surface. For each country the ecological footprint of production of a single footprint category is calculated by summing all products of that footprint category.

Ecological Footprint of Consumption

The ecological footprint of consumption for a country is estimated by calculating the ecological footprint of all that is produced in a country, then adding the ecological footprint embodied in imports and subtracting the Ecological footprint embodied in the exports:

$$EF_{equation} = EF_p + EF_I + EF_E \quad (2)$$

where:

- EF_p is the ecological footprint of production
- EF_I is the ecological footprint of imports
- EF_2 is the ecological footprint of exports

Biocapacity

Similarly, biocapacity can be measured in global hectares at any scale, from a single farm to an entire planet. The following formula details how biocapacity is calculated at the national level for each biocapacity land-use category:

$$biocapacity = A_n * \frac{Y_n}{Y_w} * EQF \qquad (3)$$

where:

- A_n is the area in country "n" for this land use category in hectares
- Y_n is the national average yield for this land use category in tons per hectare and per year

2.3 Methodologies for Performing Economic Assessments

Similar to social impact assessments, the methodology for performing economic impact assessment has not reached standardized status. However, economic impact assessment has been more researched and studied in the literature and has reached a more mature state relative to social impact assessment methods. Similar to environmental impact assessments, economic impact assessments have the benefit that input data from a generated inventory can be connected directly to its final economic impacts.

2.3.1 Life Cycle Costing (LCC)

Following a similar structure as the LCA framework, one common methodology for performing an economic impact assessment is achieved by means of a Life Cycle Costing (LCC) framework. The method is used to assess costs (subdivided into direct, indirect, contingent, intangible and external costs) related to the life cycle of a product that are directly covered by one or more actors in the product life cycle [38]. Although LCC is older than LCA, it has only been standardized for a few applications, such as Energy Management [39] and the building construction industry [40]. LCC is a compilation and assessment of all costs related to a product, over its entire life cycle, from production to use, maintenance and disposal. The motivation is that, for many products, the purchase price reflects only a minority of the costs that will be caused by the product [41].

2.3.2 Cost-Benefit Analysis (CBA)

Cost-Benefit Analysis (CBA) is the systematic and analytical process of comparing benefits and costs in evaluating the desirability of a project or programme. CBA is fundamental to government decision making and is established as a formal technique for making informed decisions about the use of society's scarce resources [42]. CBA attempts to answer the following questions [43]:

- Has an intervention delivered the intended change for the amount of resources invested?
- Would it be possible to generate more benefits for the same resources if another approach was chosen?
- In the future, should it be chosen to improve an intervention's approach or choose a different adaptation approach altogether?

To answer the previous questions, the CBA process is divided into the following 6 steps:

1. Identification of outcomes: the purpose is to understand the type of changes that are occurring (positive or negative) or have occurred since the beginning of an intervention. This exercise can be stakeholder-based or desk-based. Stakeholder-based involves asking stakeholders to express what is changing and how. Desk-based means that the hypothesis of an intervention regarding its changes is tested using data without involving any stakeholder input.

2. Quantification of gross outcomes: it involves measuring the change that has occurred for each outcome separately. This measurement has to be quantitative. Even when the measurement is qualitative, it must be expressed in a quantitative manner.

3. Measurement of contribution and counterfactual*:* the counterfactual and contribution must be measured in order to grasp the change that can be specifically attributed to the intervention you are analyzing. The term counterfactual refers to the change that might have occurred, regardless of the intervention.

4. Quantification of Impacts: the impact is mathematically defined as the net change minus the % attributed to all other factors and contributors.

5. Monetization of Impacts: CBA requires a comparison between the cost of an intervention and its benefits. To compare both sides of the equation, it is necessary to express both in a common unit, which in this case is money. This means that all impacts must be translated into money.

6. Cash flow analysis and discounting: All the data is then input into a model that accounts for when in time the costs are borne, and the benefits accruing. This process is done on

a year-to-year basis. All costs and benefits into the future are discounted in order to obtain their present value.

2.4 Motivation for Social Impact Assessments

Relative to the environmental and economic impact assessment fields, the social impact assessment field is not well studied. This can be explained by the perception of ecological aspects to be more urgent than social aspects, and by the complexity of social and economic issues and the interdependencies among them [20]. Much of the work has focused on reducing the negative environmental impacts, while the social dimension has been less covered [44]. Beyond the moral obligation of companies to have good social performance, organizations should measure their social impacts to reap long term economic benefits. Today's companies are expected to maximize their positive social impacts and to provide measurements to verify this fulfillment [45]. Experts have expressed the importance of including the social dimension simultaneously with the economic and environmental dimensions into sustainable analysis and development [46]. Including the social dimension in impact assessment methods is essential for socially sustainable product development. Including the social needs and their mechanisms guarantees the evaluation of the social contribution of the proposed solutions [47]. The evaluation of such social contributions will highlight if the contributions are the ones expected, or even more importantly, might reveal unexpected changes. Socially sustainable product development is then the development and adoption of processes that result in reduced negative social impacts along the lifecycle of the product [44].

Social sustainability is defined as the extent to which social values, social identities, social relationships and social institutions can continue into the future [48]. By means of social impact assessments, the process of defining, monitoring and employing measures to demonstrate the benefits created for the target communities through evidence of social outcomes and impacts is achieved [49].

Social impact assessment (SIA) is a methodology to assess social impacts happening at a single process and/or plant, and it is often used in the context of development projects [10]. It is also a framework for examining the expected consequences of a planned intervention on the well-being of a community [19]. The methodology is mainly used at the company level to evaluate the social performance of a company based on local information.

Among the field of social impact assessment, there are Social Life Cycle Assessments (S-LCA). An S-LCA is a systematic process using the best available science to collect best available data on and report about the positive of negative social impacts in a product's lifecycle, from extraction to disposal. It is best used for increasing knowledge, informing choices, and promoting improvement of social conditions in a product life cycle [10]. Similar to an environmental LCA, the focus of an S-LCA is the product life cycle. One of the key points of an S-LCA is to coordinate the practices of stakeholders so as to improve the behavior of the product along its entire lifecycle [50]. S-LCA and other methods for performing social impact analysis are reviewed in depth in Chapter 4, as part of the systematic mapping of the literature.

2.5 DRM as a research method

The research method followed in this work is defined as DRM, or Design Research Methodology [30]. DRM is used as a framework for organizing and developing the research plan of the work presented. The objective of using DRM is to develop and validate a decision support framework that "is grounded in scientific models and theories" [30]. Based on DRM, the aim of this work is to understand and improve the practice of social impact assessments. To achieve this, generally, the aim is to 1) have a model or theory of the existing situation, 2) a model of the desired situation and 3) a vision of the support that is likely to change the existing situation into the desired situation. The DRM framework consists of 4 stages: Research Clarification (RC), Descriptive Study I (DS-I), Prescriptive Study (PS) and Descriptive Study II (DS-II).

In the RC stage, the researchers try to find some evidence that supports their assumptions to formulate a realistic research goal. The aim is to identify the goals the research is expected to realize. This includes the definition of the research logic, the phenomena to be addressed by the study, the main research problem, main research question(s) and the working hypothesis. An additional aim is to develop an initial representation of the existing and desired situations to make explicit the current understandings and beliefs. At this stage, a set of measurable success criteria are identified, with which the outcome of the research is evaluated. The findings of the RC stage determine the focus of the next stage, the DS-I stage.

In the DS-I stage, a focused literature review is performed, based on the goal and scope defined in the RC stage. The intention of DS-I is to make the description of the current situation detailed enough to identify which parameters should be addressed to improve from the current to the desired situation.

In the PS stage, the detailed understanding of the current situation is used to inform the development of an intervention that improves it, focusing on how enhancing crucial parameters will improve it. The definition of the improved or desired situation is combined with the detailed understanding of the DS-I stage.

The aim of the DS-II stage is to evaluate the impact of the support created in the PS stage and its improvement abilities. At this stage, an evaluation plan is developed and executed for the support tool, in which the researchers aim to test the support tool for effectiveness. This feedback is then used to enhance the intervention of the support tool until the desired results are achieved.

2.5.1 Research Clarification (RC) Stage

As stated previously, the objectives of the RC stage are [30]:

- "To identify the goals that the research is expected to accomplish; the focus of the research project; the main research problems, questions, and hypothesis; the relevant disciplines and areas to be reviewed and the area in which the contribution is expected"
- "To identify a preliminary set of success criteria and measurable success criteria with which to evaluate the outcome of the research"

- “To provide a focus for the DS-I stage in finding the factors that contribute to or hinder success”
- “To help focus the PS stage on developing support that addresses those factors that are likely to have the strongest influence in the success”
- “To provide a focus for DS-II for evaluating the effects of the developed support against the goals of the research”

2.5.1.1 Research Focus and Goals

The focus of the proposed research is to develop a framework that will guide the user in the process of performing social impact assessments. The framework will be based on current methods available for performing a social impact assessment and will aid the user in determining the best roadmap to follow based on the application. The overall goal is that the framework will be used as a decision support mechanism when performing a social impact assessment.

2.5.1.2 Research Problems, Main Research Questions, and Hypothesis

Contrasted with performing environmental and economic assessments, social impacts defy quantification because there are no clear pathways established between the input and outputs. Furthermore, the field has not reached standardization, and there is significant variability in the approaches followed when performing social impact assessments. In order to tackle the aforementioned issues, this research aims to answer the following research questions:

RQ1) What are the recurring challenges and limitations faced by the current methods and frameworks available to perform social impact assessment of products?

H1: Compared to performing environmental and economic assessments, social impact assessment methods face challenges related to data availability, time and financial resources, selection of stakeholders and impact categories, and to the selection of the method used to perform the assessment.

RQ2) How can the user be guided through the social impact assessment process to succeed among these challenges?

H2: Compared to a user performing the social impact assessment without access to the decision support framework, users having access to the framework will perform a more complete and thorough assessment.

The overarching working hypothesis for this work is that there are already methods available for users to perform social impact assessments in a successful manner, so this work aims at guiding the user through the process of using those methods by providing decision support at different stages of this process.

2.5.1.3 Approach (Type of Research, Main Stages, and Methods)

The next step is to identify the type of research suitable to address the research questions and hypotheses. The DRM framework provides seven different types of research. Each research type has a purpose based on what the researcher is attempting to achieve:

Table 1: Types of design research projects in DRM framework [30].

Research Clarification	Descriptive Study I	Prescriptive Study	Descriptive Study II
1. Review-Based	Comprehensive		
2. Review-Based	Comprehensive	Initial	
3. Review-Based	Review-Based	Comprehensive	
4. Review-Based	Review-Based	Review-Based, Initial, Comprehensive	Comprehensive
5. Review-Based	Comprehensive	Comprehensive	Initial
6. Review-Based	Review-Based	Comprehensive	Comprehensive
7. Review-Based	Comprehensive	Comprehensive	Comprehensive

To perform the study presented in this dissertation, the DRM research type 6 *Development of Support and Comprehensive Evaluation* is selected. The RC stage is review-based, in which existing literature is used to determine the goals of the research project. For the DS-I stage, an exhaustive literature review is performed to understand in detail the current state of the art of the field. The learnings from this stage are then used to develop a decision support tool (comprehensive PS stage). The final step, the DS-II stage, is to develop and execute an evaluation plan for the support tool being developed.

2.5.2 Descriptive study I (DS-I) stage

A goal of the DS-I stage is to develop a detailed understanding of the current state of the art in the field of social impact assessment. This detailed knowledge is achieved by means of a literature review protocol aimed at determining the main challenges that are faced by the social assessment field. To do this, a Systematic Mapping of the social impact assessment field is performed. The systematic mapping protocol, its results, analysis and learnings are discussed in detail in Chapter 3 of this thesis. Before embarking on the systematic mapping protocol, the template shown in Appendix A was used to plan a systematic literature review protocol from Blessing [30].

2.5.3 Prescriptive study (PS) stage

The main goal of the PS Stage is the development of a novel SIA framework. This novel framework is developed through continuous iterations based on expert and novice user feedback and case study theory testing. The developed framework should support the factors identified in the DS-I stage as being crucial to improve the current state of performing SIA, which are the set of identified challenges.

2.5.4 Descriptive study II (DS-II) stage

The DS-II stage consists of developing an evaluation plan for the created intervention, which in this is case is the novel SIA framework. Chapters 5, 6 and 7 combine the PS and DS-II stages, as the activities involve gathering user feedback to evaluate the novel SIA framework while also using such feedback to make changes to enhance the framework. Chapter 5 explains the methodology used to gather expert feedback on the findings of the DS-I stage, which is part of the DS-II stage (framework evaluation plan). Chapter 6 explains in detail the methodology for gathering novice user feedback on a simplified novel SIA framework, which is part of the DS-II stage (framework evaluation plan). Chapter 7 provides the results of applying the novel SIA framework to a selected case study, which is also part of the DS-II stage (framework evaluation plan).

2.6 Conclusions

In this chapter, precursors to SIA were presented, reviewing established environmental and economic impact assessment methods, upon which SIA methods were founded. The chapter then presented how the Design Research Methodology (DRM) was used to develop the research plan for this thesis. DRM consists of four interconnected steps. In the RC step, the goals of the research project are identified. In the DS-I stage, a detailed understanding of the field being studied is pursued to identify the parameters that need to be modified to achieve success. In the PS stage, the support method is developed to overcome the challenges and barriers identified in the DS-I stage. In the DS-II stage, the goal is to develop an evaluation plan for the support in order to test its efficacy and understand its limitations. The following chapters will explain in detail the research activities involved in each of the DRM steps in order to develop the novel SIA framework, including an in-depth review of the state of the art of SIA methods which is presented in Chapter 4.

CHAPTER 3 MOTIVATION AND INITIAL RESEARCH: LIFE CYCLE ASSESSMENT TO QUANTIFY THE IMPACT OF TECHNOLOGY IMPROVEMENTS IN BIKE SHARE SYSTEMS

3.1 Motivation Case Study Introduction

Before presenting the background, literature and SIA research performed, a case study is presented that illustrates the motivation for this SIA focused dissertation. This research started with an interest in understanding the social implications of design decisions of products and systems. A Bike Sharing System (BSS) was selected as a case study. A BSS is an example of a Product Service System (PSS). The term PSS has been defined as a marketable set of products and services capable of jointly fulfilling a user's need [7]. It is also defined as a system of products and services, supporting networks and infrastructure that is designed to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models [51,52]. For a long time, enterprises have focused on providing customers with products to satisfy a certain need, where the environmental consequences were mainly related to the material decisions of the product. By adopting a PSS, companies are switching from a product-based economy to a service-based economy, in which the customer is provided with a desired service rather than a product. The increased interest in reducing the environmental impacts of products and recent developments in communication and electronics technology has resulted in a significant increase of PSS; one example of this is the BSS.

BSS are sometimes used to encourage lower transportation environmental impact by replacing vehicle trips with bicycle trips. Early BSS overcame issues of theft, lost bikes, and repairs by increasing use of electronics. Smart dock systems rely on electronic docking stations dispersed throughout a city, where users can operate the kiosks to unlock and rent a bicycle. In such systems, bicycles must be returned to a docking station at a fixed location. Current smart dock systems track which user rents each bike, allowing accountability for lost, stolen or vandalized bikes. These improvements allowed BSS to become economically feasible and enabled their recent rapid growth, from 11 systems in 2004 to approximately 855 systems in 2014 [53]. Docked systems, however, require that bicycles be returned to a docking station at a fixed location. Newer smart bike systems do not require fixed docks and are now 44% of US BSS [54]. In a smart dock BSS, the central docking station contains all the electronic equipment needed to manage the shared bikes, such as mobile Global Positioning Systems (GPS), Information Technology (IT), and solar panels. In 2015, researchers estimated there were almost a million BSS bikes worldwide, with three-fourths of those in China [55]. Smart bicycle systems have docking stations that are not electronic. Each bicycle has its own locking and electronic system that replaces the kiosk. These smart bikes often have a dedicated touchpad, screen, and solar panel. By the year 2016, 31% of all US BSS were smart bike BSS. In the United States, an additional 57,500 bicycles were added from 2016 to 2017, of which 77% were smart bikes [54]. In 2018, China had between 16-18 million BSS bicycles [56].

Use of smart bike instead of smart dock BSS has not led to reliable ridership increase but has addressed the needs of different types of users. D.C. Capital Bikeshare reported that adding smart bike systems did not reduce smart dock system ridership, but by incorporating both systems, they increased the overall diversity of the BSS user population [57]. A Virginia Tech Survey of Washington, D.C. smart dock and smart bike BSS users revealed that smart bike users were more racially diverse, had a higher proportion of women riders, and had a lower income [58].

Evidence indicates, however, that smart bike BSS users may have less sustainable usage patterns. In the United States, smart bike systems averaged 0.3 rides per bike per day, while smart dock systems averaged 1.7 rides per bike per day in 2017 [59]. In Seattle smart dock systems demonstrate usage patterns that correlate with commuting rush hours, while smart bike systems exhibit trip patterns suggestive of recreational use [59]. In Washington, D.C., smart bikes have more geographically diverse usage, most likely due to removing the need to begin and end each trip at docking stations [58]. Despite fulfilling different functional needs, in Washington, D.C. smart dock and smart bike BSS trips are both generally less than 3 miles. Without strong evidence of increased ridership, increasing the use of electronics may undermine the environmental sustainability of BSS. Experts caution that there is no standard method for evaluating the overall success or failure of a city's BSS implementation [55,60,61].

Based on the essential role of technology in the success of BSS, the following research question is raised: *how does the use of advanced technology and electronics affect the environmental sustainability of a BSS*? By means of an environmental Life Cycle Analysis (LCA), the difference in the environmental impact of the production, use, and disposal phases of private bikes, a smart dock, and a smart bicycle BSS are analyzed. The LCA was conducted with the functional unit of per km biked. By using the functional unit per distance traveled, the results can be compared to the impact of other modes of transportation. As a secondary benefit, this functional unit emphasizes the importance of the shared travel aspect of the BSS.

The LCA determines the environmental impact per kilometer among a smart bike, smart dock, and private bicycle for the production, repair, disposal, and rebalancing lifecycle phases. This assessment achieves the following goals: first, this case study is the first published LCA of a smart bike known to the author; second, the impact of a smart dock and smart bike system are compared to determine how many more rides per bike per day are necessary to overcome the increased environmental impact of switching in a city; third, an estimate of the total increase in impact is provided, if the evolution from smart dock to smart bike is completed in the United States, with a caution that it may undermine the environmental sustainability of the BSS; fourth, the LCA results are leveraged to provide recommendations as to the preferred configuration based on the number bikes fitted per dock; and finally, because these results indicate that smart dock systems may not be environmentally preferable without additional advances in BSS smart bike technology, recommendations are made for future technology development efforts to reduce the environmental impact of future smart bike BSS. The following sections of this chapter describe prior studies of bike-sharing environmental impact, the method of data collection and analysis, the results and conclusion of this case study and thesis motivation.

3.2 Background

3.2.1 Benefits of BSS and Need for a Systematic Method to Evaluate BSS

BSS growth is motivated by city, personal, and environmental benefits as a substitute for fossil-fuel powered transportation [62]. When announcing the implementation of their BSS, officials from Barcelona, Lyon, and Paris referred to BSS as a sustainable transportation option [61]. In a recent survey, 40% of BSS users in Melbourne, Australia responded that a reason they use the system is for the environmental benefits it provides [63]. BSS promote economic growth by encouraging redevelopment to increase real estate value, helping companies secure more talented workers and increasing retail visibility and sales [64–66]. BSS also improve the physical, social and mental health of communities by increasing access to transportation and recreational facilities [67–71]. Increased exercise improves public health and reduces expenditure on healthcare [66].

Bike sharing, however, increased the overall motor vehicle usage when the effect of bike rebalancing was considered in London, UK [63]. Rebalancing refers to the process in which vehicles and personnel relocate bicycles to compensate for asymmetric demand patterns between BSS stations. The need for an objective evaluation of the environmental impact of BSS has been identified in the literature [55,60,61]. In this study, the environmental impacts of the smart dock and smart bicycle BSS are benchmarked with the impact of a private bicycle.

3.2.2 *Previous Bicycle LCAs*

Previous LCA studies on personal bicycles highlight the production phase as the one with the highest environmental impact (excluding off-set vehicle emissions), relative to the other phases of the lifecycle, but do not consider factors unique to BSS, such as the evolution of bicycle technology or the role of rebalancing bicycles [72–74]. Their results show that the component with the greatest environmental impact is the aluminum bicycle frame. The increased impact of the aluminum bicycle frame motivated a comparative LCA study using other materials for the bicycle frame, such as bamboo [31]. The results from these studies provide a reference to validate the case study results for the private bicycle environmental impact.

Amaya et al. [75] aimed to provide an initial approach toward assessing the environmental impact of Product Service Systems (PSS) using LCA. The focus of their study was to evaluate how variations in the system design parameters of a PSS affect its environmental impact. Using a BSS as a case study, different system scenarios were analyzed to understand how the intensification in the use phase of PSS affects its sustainability. The main system design parameters that were varied were the total number of bicycles in the system, the amount of maintenance time, and bicycle rebalancing. Their results showed that a reduction in the environmental impact of the PSS is achieved by increasing the amount of use given to the BSS. The authors highlight that the intensification in the use phase of a PSS is what provides an environmental benefit when compared with the classical product sale model, which has a single-use phase. Their study, however, did not include details on the Life Cycle Inventory (LCI) for the BSS, and it only focused on a smart dock system. The LCI refers to the data collection portion of the LCA. It consists of a detailed accounting of the materials and components of the system of interest [76].

Numerous studies focus on the BSS rebalancing procedure and costs. One study estimated that bike rebalancing required approximately 2.2 km of car travel for every 1 km of London BSS travel [63]. Wald estimated that 20-30 researchers have rebalancing as a central part of their research [77]. Improving the rebalancing process directly affects BSS environmental and economic impacts, which is why many current studies have focused on analyzing or increasing the efficiency of rebalancing approaches [55,78,79]

This case study expands system design knowledge and the contributions of previous LCA studies on bicycles and BSS by providing an evaluation of the environmental impact for both smart bike and smart dock BSS, including empirical component data. BSS rely on the use of technology for their success, and it is important to have a better understanding of how these technological design decisions affect the environmental sustainability of BSS.

3.3 Methodology

3.3.1 LCA Goal, Scope, and Functional Unit

The purpose of this LCA is to evaluate the environmental tradeoffs of increasing use of electronics per bike between the smart dock and smart bike BSS. To achieve this goal, the selected LCA scope is a cradle-to-grave for a smart bike, smart dock and private bicycles in a hypothetical city X over ten years. The cradle-to-grave analysis includes the production, disposal, and use phases. Although previous LCA studies on personal bicycles highlight the production phase as the one with the highest environmental impact relative to the other phases of the lifecycle [72–74], BSS add an additional environmental impact that personal bicycles do not incur because of the inclusion of electronics and because the use phase of BSS requires rebalancing operations. There is no evidence that increased electronics change the percentage of bicycle km that replace vehicle km (i.e. the percentage of rides that replace cars is not going to increase relative to other modes). When comparing a smart dock and smart bike BSS, one key difference is how technology is being implemented in each arrangement. In a smart dock BSS, a central docking station contains all the electronic equipment needed to manage the shared bikes. In a smart bike BSS, each bicycle is fitted with an electronic unit, eliminating the need of a central docking station to manage the shared bicycles. By performing an LCA for the two smart dock types, the different methods of implementation for the electronics can be compared with regard to their effect on the overall environmental impact of each BSS arrangement. The goal of this case study is not to validate the environmental benefits of using a bicycle as a means of transportation, but rather to have a better understanding of the tradeoffs that exist when implementing technology and electronics in BSS with respect to their environmental impact.

To compare the environmental impact of the private bike and two types of BSS, the total environmental impact is normalized by the functional unit km of bike travel. The environmental impact is calculated as the total GHG emissions in kg CO_2 Eq for the production, use, and disposal phases. For the three systems, the disposal scenario is similar, where 100% of the components are disposed in a landfill (0% recycling).

3.3.2 Life Cycle Inventory (LCI) Data Collection

The LCI for the two BSS bicycles and the private bicycle were obtained from multiple data sources. To gather the data for the smart bike BSS bicycle, a U.S. BSS operating company provided access to the individual smart bicycle BSS components. The components of this smart bicycle BSS were individually weighed using a scale and classified according to their material type. The measurements were taken with a Grawor Digital Luggage scale, which has a maximum capacity of 50 kg. The digital readability for this scale is 5 grams for measurements between $2x10^{-2}$ and 10 kg and 10 grams for measurements above 10 kg. The data for the private bicycle was gathered from a bicycle starter program on a U.S. college campus. The private bicycle components were individually weighed and classified according to their material type.

Without physical access to an electronic docking station, the most relevant electronic components were estimated using data from the literature. Numerous attempts were made to contact BSS operating companies in the Southeast Region of the United States, but the companies expressed their unwillingness to provide us access to an electronic docking station. The goal was to access at least one electronic docking station to gather empirical data about the electronic components and use this data for the Life Cycle Inventory. Instead, a literature review of electronic stations based in academic journals, design patents of docking stations for BSS, and manufacturing companies of electronic kiosks was conducted to determine the components and sizes for a docking station and kiosk. Each document was reviewed, and a list of the most common components was determined as the following: a solar panel, a battery, a printed circuit board (PCB), a display screen, a keypad, a radio communication module and a Global Positioning System (GPS) Module.

For smart docks, the estimated solar panel area, the weight of the battery, and the printed circuit board weight are all divided by 10 to obtain the values for each smart dock bicycle. Ten bicycles per docking station is the average based on data from 52 BSS systems located in the United States [80].

3.3.3 Rebalancing Impact Estimation

Rebalancing refers to the process in which personnel relocate bicycles to compensate for asymmetric demand patterns between BSS stations. Some cities have attempted to avoid using fossil fuel vehicles to perform rebalancing by incentivizing users to reposition the bikes [81]. Due to the environmental and economic impacts of the rebalancing, many current studies have focused on analyzing or increasing the efficiency of rebalancing approaches [55,78,79]. These asymmetric flow patterns can be driven by topography or mismatches in the underlying demand for bicycles [60].

Currently, rebalancing data are only available for smart dock BSSs in Washington, D.C., London, Minneapolis-St. Paul, and Melbourne [63]. Although smart bike operators provide incentives for riders to return bikes to designated areas, smart bike systems might be more distributed than smart dock systems, requiring greater amounts of rebalancing. Using the smart dock rebalancing distance for the smart bike rebalancing in the LCA presented in this study thus provides a conservative estimate.

The impact of rebalancing per km biked depends on the number of bikes in the system, system size, types of vehicles used for rebalancing, and how often rebalancing occurs. This case study evaluated the rebalancing impact for a fictional city referred to as City X. City X has 1240 bicycles, 804,900 trips annually, and requires 105,582 km of rebalancing. City X was created by averaging the reported values for Melbourne, Washington, D.C., and Minneapolis-St. Paul [63]. A database from the United States Life Cycle Inventory (USLCI) that represents the average U.S. airborne emissions for operating a gasoline-powered light commercial truck (6.79×10^{-1} kg CO_2 eq/km driven) was used to represent the environmental impact of the rebalancing vehicle [82].

3.3.4 Maintenance Impact Estimation

Table 2: List of components that require replacement and their service life (km) for the private bicycle, the smart dock BSS bicycle, and smart bike BSS bicycle [83–87].

Component	Service life (km)	Private bicycle	Smart bicycle BSS	Smart dock BSS	Material type	Weight (kg)
Rear Wheel Internal Hub Gear	8000		✓		Alloy Steel and Aluminum	1.66
Front Wheel Hub Roller Brake	9600		✓	✓	Alloy Steel and Aluminum	0.58
Rear Wheel Hub Roller Brake	9600		✓	✓	Alloy Steel and Aluminum	0.58
Chain	2400	✓		✓	Steel	0.28
Cassette	4800	✓		✓	Steel	0.34
Tires	2400	✓	✓	✓	Rubber	0.44

The BSS maintenance estimation is based on manufacturer user manuals and grey literature information sources for the drivetrain and braking systems [83–87]. A large variation in the reported life expectancy values for the drivetrain and braking components was found, so the average values were used. Table 2 shows the assumed service life of the components used in the private bicycle and the two BSS bicycles. The maintenance impact is calculated based on the number of component replacements required in the 10-year time frame.

Using the component data shown in Table 2, the environmental impact of each of the components is determined at the endpoint and midpoint levels. At the midpoint level, the environmental impact is calculated as total GHG emissions in kg of CO_2 Eq The values are 8.30 kg of CO_2 Eq for the private bike, 28.39 kg of CO_2 Eq for the smart bike, and 23.91 kg of CO_2 Eq for the smart dock bike respectively. At the endpoint level, the total environmental impact for the human health, ecosystem and resources impact categories [88,89] are 1.27 Pts for the private bike, 3.36 Pts for the smart bike and 3.34 for the smart dock bicycle respectively.

3.3.5 Conversion of Total Impact Estimation to Functional Unit

Once the environmental impact from each of the lifecycle phases is calculated, it is converted into the functional unit of kg CO_2 Eq per km biked. The temporal scope for this analysis is a 10-year period; it is assumed that the average BSS traveled distance is 2.49 km [60] per trip, and that the private bike was ridden 500 times per year. Five hundred trips per year assumes that the user is substituting a private bike for the function of commuting, a major demand source for BSS [59]. The user is assumed to commute twice a day, five days a week, for fifty weeks per year. Of note, these calculations extrapolate 1 year out to 10 years to estimate the total life cycle impact. Changes in ridership patterns, the number of bikes in City X, or rebalancing strategy over 10 years would affect this impact and are not taken into consideration in this study.

3.4 Results and Discussion

3.4.1 Bill of Materials and LCI Data

Table 3: Life Cycle Inventory (LCI) data for smart bicycle and smart docking BSS.

Material/ Component	**Amount**			**Unit**	**Comments**
	Smart Bike	**Smart Dock**	**Private Bicycle**		** Assumed 10 bicycles per docking station
Aluminum	12.56	12.56	8.53	kg	Extrusion of Aluminum (Frame), Arc Welding, Manufacturing
Alloy Steel	10.28	10.28	3.63	kg	Steel Product Manufacturing
Foam	0.03	0.03	0.03	kg	Foam Blowing
Plastic	1.70	1.70	1.75	kg	Injection Molding
Rubber	0.85	0.85	1.55	kg	Injection Molding
Stainless Steel	1.28	1.28	1.28	kg	Steel and Chromium Product Manufacturing
Steel Wire	0.10	0.10	0.10	kg	Steel Wire Drawing
Electronic System	**Smart Bike**	**Smart Dock**	**Private Bicycle**		
Photovoltaic Cell	0.012	0.019**	NA	m^2	The average value is estimated from images for 9 different BSS. The average value of the solar panel area is then divided by the number of bikes in the smart dock station
Printed Circuit Board	0.30	0.02**		kg	Estimation for Printed Circuit Board (PCB) is based on the work of Kasulaitis et al. [90]
Lithium-Ion Battery	0.25	0.35**		kg	Weight estimation is based on a similar solar panel area to battery storage energy capacity

					ratio between the smart bike and smart dock system.
Docking Station	**Smart Bike**	**Smart Dock**	**Private Bicycle**		
Alloy Steel	30	30	NA	kg	Steel Product Manufacturing

The RECIPE 2008 [91] impact results are provided for the endpoint categories of human health, ecosystems, and resources, in total impact Pts and for the midpoint category climate change. Endpoint categories provide an overall comparison of the three systems, and climate change in terms of CO_2 equivalent may be more relevant from a policy perspective. For this case study, it is assumed that most smart dock and smart bike component weights are equivalent. The drivetrain for the smart bike model measured empirically in this study uses a driveshaft instead of a chain and cassette to be more robust. The driveshaft has a higher environmental impact, but is less than 2% of the total impact. Regardless of the environmental impact approach (GHG emissions or endpoint impacts), the maintenance portion of the use phase accounts for less than 3% of the total impact. Text and image documentation indicated that the display screen, the keypad, the radio communication module, and the GPS module were similar in size between the two BSS configurations. Based on this information for the smart dock BSS, only the solar panel area, the battery pack weight, and the PCB weight required estimation. The solar panel area of the electronic docking stations was determined by averaging online images from nine different BSS. The IC Measure software package was used to estimate the average solar panel area as 0.187 m^2 [92]. A BSS smart dock battery pack size was not available in the literature. It was assumed that the ratio between the energy storage capacity and the solar panel area size for a smart dock station is the same for the smart bike bicycle. Under this assumption, the docking station is estimated to have the energy capacity of 75 Panasonic NCR 18650 Li-ion batteries [93]. This battery model is used for a wide range of products, from portable remote-controlled vehicles and flashlights to high-performance battery packs in electric vehicles. The total battery pack weight is estimated to be 3.48 kg.

For the PCB, the list of docking station electric components from the literature suggests similarity to the components of a personal computer PCB. Kasulaitis et al. [90] estimate that a personal computer PCB weight is 0.228 kg (estimated in 2015). The resulting weight of 0.228 kg is then divided by 10 to obtain the total PCB weight per smart dock bike. The resulting values for the solar panel area, the battery pack weight, and the PCB weight are shown in Table 3 as 0.019 m^2, 0.348 kg, and 0.023 kg, respectively.

Table 3 shows the LCI for the smart bike, smart dock, and private bicycle. The higher total impact of the BSS bicycles is due to an emphasis on durability, achieved with larger elements and special components such as nonremovable seats [81]. Table 3 also shows the LCI data for the stand-alone electronic system used in the smart bicycle system. Regarding the smart bike BSS, the only component that required estimation was the PCB weight. The weight of the battery and the solar panel area were measured empirically by the researcher. The researcher weighed the electronic unit fitted in each smart bicycle that included the PCB, the LCD screen, and a plastic case that protected all of the components. To estimate the weight of the PCB from the total weight of 0.86 kg, the material composition results from the work of Kasulaitis, Babbitt, Kahhat, Williams, and Ryen [90] were used. Their work suggests that 35% of the total weight is attributed to the PCB, which results in a weight of 0.3 kg. The docking stations for both BSS types are assumed to be made of steel. The smart bike station consists of modular steel designs that do not require permanent fixtures. The docking station weight was measured empirically as 30 kg, and it was added to the LCA analysis for both BSS types.

3.4.2 Production Phase Impact Results

Table 4: Components that account for the most environmental impact. Environmental impact results are shown for GHG emissions and the sum of the endpoint categories of Human Health, Ecosystems and Resources for the production phase for the private bike, smart bike, and smart dock BSS (10 bikes per dock).**

Component	Private Bicycle		Smart Bicycle BSS**		Smart Dock BSS**	
	kg CO_2 Eq	% of Total	kg CO_2 Eq	% of Total	kg CO_2 Eq	% of Total
Circuit Board	--	--	545.70	37.40%	0.32	0.10%
Solar Panel	--	--	573.90	39.30%	139.40	29.10%
Bicycle Frame	70.72	78.80%	175.70	12.00%	175.70	36.70%
Alloyed Steel	6.04	6.70%	147.80	10.10%	147.80	30.90%
Total	**76.80**	**85.50%**	**1460.00**	**98.80%**	**478.60**	**96.80%**
Component	**Private Bicycle**		**Smart Bicycle BSS****		**Smart Dock BSS****	
	Pts	**% of Total**	**Pts**	**% of Total**	**Pts**	**% of Total**
Circuit Board	--	--	50.40	34.10%	3.82	6.97%
Solar Panel	--	--	54.60	36.90%	8.51	15.55%
Bicycle Frame	8.24	69.08%	19.10	12.90%	19.10	34.90%
Alloyed Steel	1.51	12.65%	21.63	14.60%	21.63	39.50%
Total	**9.75**	**81.73%**	**145.70**	**98.50%**	**53.10**	**96.90%**

Table 5 shows the production phase GHG in kg CO_2 Eq using RECIPE 2008 [91] and the percent of the total environmental impact (%) for the PCB, the solar panel, the bicycle frame, and steel alloy components, which account for greater than 95% of the total production phase environmental impact for both BSS types. The PCB and the solar cell dominate the overall environmental impact for the smart bicycle BSS, while for the smart dock BSS, the bicycle frame has a higher contribution due to the reduced amount of electronics required per bicycle relative to the smart bicycle BSS.

Table 5: Production phase GHG emission impact in kg CO_2 Eq per bicycle at the climate change and ozone depletion midpoint categories and Production Phase impact for the Human Health, Ecosystems and Resources Endpoint Categories for the private bike, smart bicycle, and smart dock BSS (10 bikes per dock).**

Midpoint Category	**Unit**	**Private Bicycle**	**Smart Bicycle BSS**	**Smart Dock BSS****
Climate Change	kg CO_2 Eq	89.63	1459.00	478.35
Ozone Depletion	kg CO_2 Eq	0.07	0.58	0.19
Total	kg CO_2 Eq	89.70	1460.00	478.60
Endpoint Category	**Unit**	**Private Bicycle**	**Smart Bicycle BSS**	**Smart Dock BSS****
Human Health	Pts	4.97	77.35	25.04
Ecosystems	Pts	2.06	23.26	9.40
Resources	Pts	4.90	47.29	20.31
Total	**Pts**	**11.93**	**147.90**	**54.75**

Table 5 shows a comparison of the environmental impact per bicycle for the two midpoint categories and three endpoint categories that make up the total GHG emissions for the private bicycle and the two BSS. The production phase GHG emissions for a smart bicycle is 1460 kg CO_2 Eq and 478.60 kg CO_2 Eq for a smart dock system. Based on these results, the smart bicycle BSS production phase impact is approximately 3.7 times that of a smart dock BSS. The endpoint categories show a similar behavior. The smart dock bicycle has approximately 2.7 times the environmental impact of the smart dock bicycle. The increased environmental impact of the bikeshare system bikes, relative to the private bike, is due to the electronic system that is incorporated into BSS bikes.

The production results provide the basis for the recommended technology development agenda. The production phase GHG emissions for the electronic components were 7,453 kg CO_2 Eq/m^2 for the solar panel, 13.95 kg CO_2 Eq/kg for the PCB, and 1.01 kg CO_2 Eq/kg for the battery. BSS technology developers should target the solar panel as the main component for reducing the environmental impact of the electronics, followed by the PCB and the battery. The solar panel impact could be reduced by improving solar panel technology or minimizing the required electrical loading of the battery. For example, the solar panel could be used only to initiate a bike checkout, and some of the user's pedal energy could be harvested to recharge the battery during trips, transmit location data, and support other energy intensive operations.

The breakeven point for system planners in choosing one system or another relies on the system density, population density, and likelihood of residents biking. After placing five or more bikes per smart dock station, the kilogram CO_2 Eq/bike for a smart dock system is less than a smart bike system. Smart bikes are preferable when systems required fewer than five bikes per station area, less than 0.2–0.4 km. Docks are preferable when a system has more than five bikes per station and stations are 0.2–0.4

km apart. The Institute for Transportation and Development Policy [94] recommends 10–30 bikes per 1,000 residents. Consequently, smart docks become preferable at a population density between 1,030 residents/km^2 (in a bike friendly city) and 3,100 residents/km^2 (in a city that is less likely to bike).

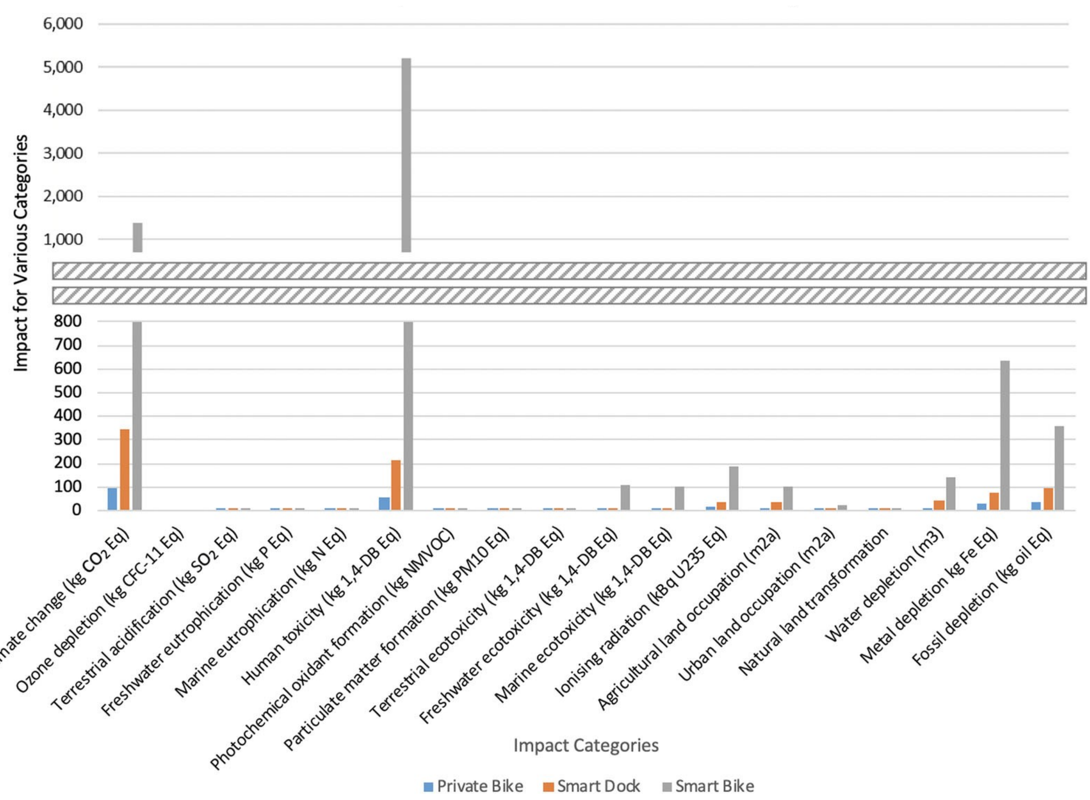


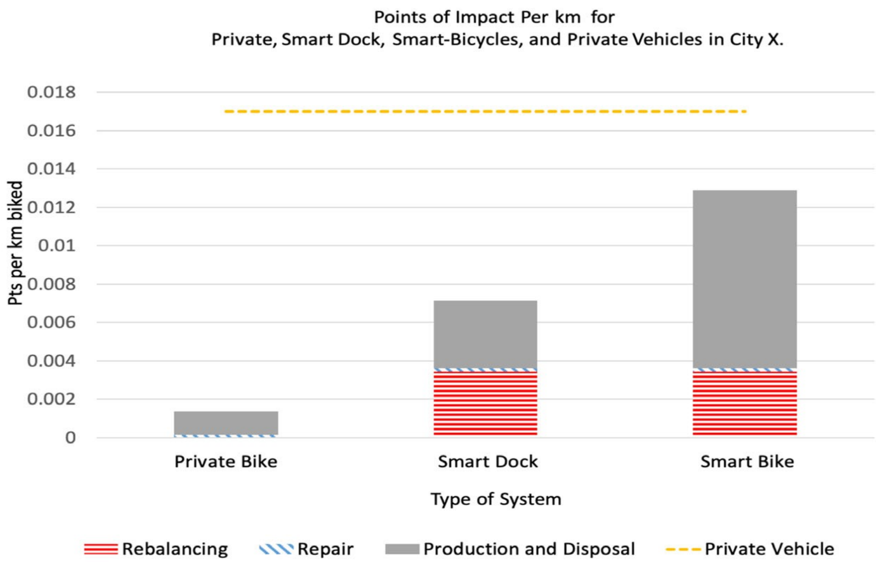
Figure 1: Production phase midpoint environmental impact for private, smart dock, and smart bicycles

Figure 1 shows the midpoint impact categories for the production phase of the private bike, smart dock and smart bikeshare system bicycles. A significant impact is seen for the smart bikeshare system bike for the climate change, human toxicity, metal depletion and fossil fuel depletion midpoint impact categories relative to the smart dock and private bicycles. This increased impact is attributed to the electronic unit used in smart bikeshare system bikes.

3.4.3 Cradle to Grave Impact Results

Figure 2 shows the environmental impact per kilometer biked for the three evaluated designs with all cradle-to-grave phases included. The smart bike resulted in the highest environmental impact per functional unit, with a value of 0.013 kg CO_2 Eq (0.013 Pts) per kilometer biked over its lifetime, compared to 0.068 kg CO_2 Eq (0.0071 Pts) per kilometer biked for the smart dock and 0.0015 kg CO_2 Eq (0.0024 Pts) per kilometer biked for the private bike. The additional impact of the electronics in the BSS results in a significant difference in GHG emissions from private bicycles. The impact of a private passenger vehicle 0.186 kg CO_2 Eq (0.017 Pts) per kilometer is plotted for comparison. The three bicycle solutions provide a net environmental benefit, but the vehicle substitution rate to bicycle must be evaluated to provide the complete picture.

System Type	Production (Points per km biked)	Maintenance (Points per km biked)	Rebalance (Points per km biked)	Disposal (Points per km biked)	Total (Points per km biked)
Private Bicycle	$8.60X10^{-4}$	$1.32X10^{-4}$	NA	$1.23X10^{-4}$	$1.12X10^{-3}$
Smart Bike	$9.15X10^{-3}$	$1.75X10^{-4}$	$3.43X10^{-3}$	$1.55X10^{-4}$	$1.29X10^{-2}$
Smart Dock**	$3.39X10^{-3}$	$1.74X10^{-4}$	$3.43X10^{-3}$	$1.57X10^{-4}$	$7.15X10^{-3}$



System Type	Production (kg CO_2 Eq per km biked)	Maintenance (kg CO_2 Eq per km biked)	Rebalance (kg CO_2 Eq per km biked)	Disposal (kg CO_2 Eq per km biked)	Total (kg CO_2 Eq per km biked)
Private Bicycle	$6.46X10^{-3}$	$5.99 X10^{-4}$	NA	$4.09X10^{-4}$	$7.47 X10^{-3}$
Smart Bike	$9.03X10^{-2}$	$1.76 X10^{-3}$	$3.58 X10^{-2}$	$1.62X10^{-3}$	$1.29 X10^{-1}$
Smart Dock**	$2.96X10^{-2}$	$1.48 X10^{-3}$	$3.58 X10^{-2}$	$1.48X10^{-4}$	$6.83 X10^{-2}$

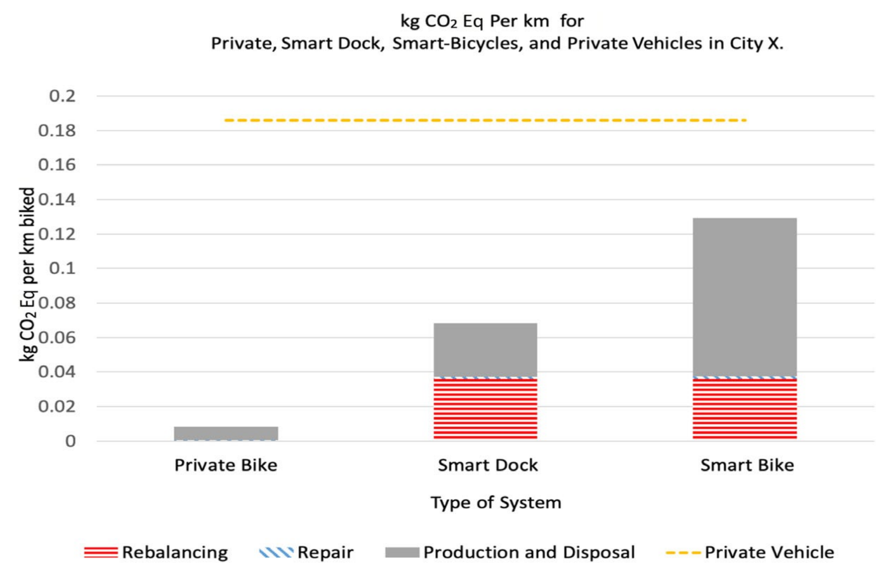


Figure 2: Impact per km biked for private bicycle, smart dock, and smart bicycle BSS.

The impact per kilometer will further decrease if the offset emissions from vehicle substitution rate are included. Vehicle substitution rate is the percentage of BSS trips that would otherwise have been taken by private automobile. Optimizing bike sharing in European countries reports vehicle substitution rates as high as 79%, whereas other studies have reported rates as a low as 1–2% [63,65,95]. The lowest vehicle substitution rate of 1–2% may be related to an overall shift in the modal share of cities, and variance in vehicle substitution rate between the examined cities is likely related to the transportation mode mixture within each city. For 21 cities in the United States, Canada, and Europe, the average vehicle substitution rate is 22% [60,63,65,95,96]. If only peer-reviewed sources are used, the average vehicle substitution rate of the remaining nine cities drops to 9.7%, with a maximum reported vehicle substitution rate of 21%. Using these minimum and maximum vehicle substitution rates reduces the per kilometer impact by 0.018–0.15 kg CO_2 Eq (0.0017–0.013 Pts) per kilometer biked. At a 22% vehicle substitution rate, the expected reduction is 0.040 kg CO_2 Eq (0.0037 Pts) per kilometer.

To result in a net positive environmental impact, a vehicle substitution rate of 38% (kg CO_2 Eq) or 43% (Pts) is required for the smart dock, and a rate of 71% (kg CO_2 Eq) or 76% (Pts) is required for smart bike. When evaluating the minimum vehicle substitution rate (worst case impact scenario), only the private bike usage results in a net environmental reduction (–0.0099 kg CO_2 Eq [-4.7×10^{-4} Pts] per kilometer biked). These large necessary vehicle substitution rates illustrate the importance of modal shift from high-impact modes of transportation, like private vehicle to BSS, compared to users shifting from other sustainable modes of transportation, such as private bike or walking.

Using the impact per kilometer biked in City X, the additional number of rides needed for a smart bicycle system to have the same impact as an equivalent smart dock system is estimated. A replacement smart bike system would need to increase demand from 1.7 daily trips per bike to 3.28 daily trips per bike. Thus, ridership would need to increase 1.8 times. In contrast, there is evidence that smart bike systems have less ridership per bike than smart dock systems. In the United States, smart bike systems averaged 0.3 rides per bike per day, whereas smart dock systems averaged 1.7 rides per bike per day in 2017 [54].

Table 6: Summary of BSS Arrangement Environmental and System Characteristics.

Topic	Smart Bike System	Smart Dock System
Production Phase Environmental Impact	Production phase environmental impact is high due to amount of electronics fitted per bike. GHG: 1,460 kg CO_2 Eq Endpoint total: 148 Pts	Centralized electronic system reduces the environmental impact per bike relative to smart bike. GHG: 479 kg CO_2 Eq Endpoint Total : 55 Pts
Complete Lifecycle Environmental Impact	Ridership would need to increase by 1.8 for a smart dock system or vehicle substitution rate of 71%. GHG: $1.3 \times 10{-}1$ kg CO_2 Eq/km Endpoint total: $1.3 \times 10{-}2$ Pts/km	Lower environmental impact per kilometer ridden than smart bike. Requires vehicle substitution rate of 38%. GHG: $6.9 \times 10{-}2$ kg CO_2 Eq/km Endpoint Total: 7.2 x 10-3 Pts/km
Station Density or Number of bikes per Station	Impact per bike is consistent when varying the number of bikes per docking station. Should be considered when less than five bikes are fitted per docking station area or for cities with fewer than 3,000 residents/km^2.	Results suggest that the smart dock system provides an environmental benefit when having 5 or more bicycles per docking station area. Should be considered for cities with more than 1,000 residents/km^2.
Bicycle Rebalancing	The rebalancing operation is a significant source of environmental impact on both BSS types. Regardless of the BSS type, it is	

	recommended to adopt low-emission or even zero-emissions rebalancing procedures. GHG: $3.6 \times 10{-}2$ kg CO_2/km Endpoint Total: 3.4 x 10-3Pts/km
Electronic Components	The LCA results show the solar panel has the highest environmental impact at 7,453 kg CO_2 Eq/m^2, followed by the PCB at 14 kg CO_2 Eq/kg, and finally the battery at 1 kg CO_2 Eq/kg. The solar panel impact could be reduced by improving solar panel technology or minimizing the required electrical loading of the battery.

3.5 Sensitivity Analysis

Two sensitivity analyses were performed, one testing the assumptions of rebalancing and a second testing the vehicle substitution rate. For rebalancing, the sensitivity was tested of breakeven ridership levels to the assumption that the rebalancing requirement is the same for smart dock and smart bike systems. A smart bikes best-case scenario of a 90% reduction in rebalancing requirements for City X was tested, yielding 10,558 km rebalancing for smart bike and 105,582 km rebalancing for smart dock. Smart bikes still have a higher impact of 0.0912 kg CO_2 Eq/km compared to 0.0611 kg CO_2 Eq/km. Smart bikes in the best-case vehicle substitution scenario would still require an increased ridership of 2.34 trips per bike per day to result in equal impact.

To test vehicle substitution rates, scenarios were tested with the highest observed vehicle substitution rate (79%) for the smart bike and the lowest reported vehicle substitution rate (1%) for the smart dock. In this best-case scenario for smart bikes, smart bikes resulted in more CO_2 savings, –0.0665 versus –0.02122 kg CO_2 Eq/km traveled. For equivalent net impact, the smart bike requires a 35% higher substitution rate than the smart dock. This result supports earlier evidence for the importance of a high vehicle substitution rate for overall BSS sustainability.

To ensure the parameters of City X did not drive the final results, the analysis was repeated with the reported parameters for Melbourne, Washington, D.C., and Minneapolis-St. Paul. The smart bike impact ranged from 2.2 to 3.6 times larger than the smart dock impact for those cities, consistent with the results for City X. Assumption of similar ridership levels for smart dock and smart bike systems in City X may provide a conservative estimate. Although 44% of the U.S. BSS bicycles in 2017 are smart bike, they only accounted for 4% of the trips taken [54]. Table 6 summarizes the key findings of this study with respect to the environmental impact for both BSS types. It provides the key characteristics of each systems and their strengths and weaknesses.

3.6 Conclusions

This study evaluated the environmental tradeoffs of increasing use of electronics of smart bike BSS relative to smart dock BSS. This was accomplished with a comparative LCA of the production, disposal, and use phases of a smart bike BSS, a smart dock BSS, and private bikes. At the time it was performed, this study was the first to the author's knowledge containing LCI data for smart bike systems. Shifting to smart bike in the analysis requires an increase in ridership by a factor of 1.8 to overcome the increased environmental impact of electronics in smart bikes. The smart bike BSS is the preferred configuration when there are less than five docks per station. Smart bikes are appropriate for cities with lower population density, less than 1,000 residents/km^2 if the city is bike friendly and less than 3,000 residents/km^2 if the city is less bike friendly. Otherwise, smart docks are more environmentally preferable. Future technology development efforts should reduce environmental impact of smart bike BSS by focusing on the solar panel and PCB. Using lower impact solar technologies and reduce the power requirements are two viable methods.

3.7 Motivation for Focus on Social Impact Analysis

The results of this BSS case study show the significant environmental impact resulting from the increased use of technology in smart bike systems. Ironically, that increased use of technology and electronics is what has resulted in the surge of BSS in the U.S. and worldwide. In addition to the environmental impacts resulting from the increased use of electronics, it should be considered how such design decisions affect the accessibility of BSS. In the US, the majority of BSS users are higher-income, white males [97]. How is the design of the BSS bikes affecting these user demographics? Numerous studies have examined the significant inequity levels of BSS users. Such inequity is attributed to liability costs associated with a BSS bike, or to the inability to operate smart bikes due to not being the owner of a smartphone or having reliable internet access [97]. Bikeshare systems show the importance of considering social criteria, such as accessibility and equity in the design process of a product. The BSS case study thus motivated the research presented in this thesis, whose main goal is to understand existing social impact assessment (SIA) methods and to study the possibility of using such methods during the design process of products.

CHAPTER 4 SYSTEMATIC MAPPING OF SOCIAL IMPACT ASSESSMENT FIELD

4.1 Introduction

A recent increase in the number of SIA studies has resulted in a large body of work that appears to lack standardization. An approach to address this issue is to analyze the large collection of results and studies in SIA with the purpose of integrating individual findings, to establish a detailed understanding of the field by means of a systematic evidence synthesis method. Evidence synthesis methods follow a rigorous and transparent process, aiming to reduce reviewer selection and publication bias, and to enable the reader to review all of the decisions made in order to screen the selected articles [27]. A well-regarded evidence synthesis method is the systematic review. A systematic review is defined as “a structured evaluation of the literature with the goal of answering a specific research or application question with a synthesis of the best available evidence.” [14]. This method reduces the subjectivity in drawing conclusions [24,28], reveals trends, relationships and gaps in the literature in order to synthesize, organize and evaluate what is known and what is unknown within a particular field [29].

Although a systematic review is a powerful method for performing evidence synthesis, its feasibility to answer open frame questions such as the one presented in this study, is questionable. Open framed questions require the inclusion of evidence from heterogeneous sources, which may difficult the result synthesis process presented in the systematic reviews [27]. Answering this research question involves the collection of information sources that may not allow a quantitative synthesis to answer the research question. Based upon the nature of the study, the research team opted for performing a systematic mapping of the social impact assessment field. By means of a systematic mapping, the objective of this study is to determine the state of the knowledge of the social impact assessment field, identify research gaps for future research directions, and to identify a set of fundamental challenges involving the application of social impact assessments. The research question investigated through the systematic mapping is the following: "What are the current methods available to perform social impact assessments, and how have they been implemented?" Details about the systematic mapping procedure are presented in the Methodology section of this chapter to ensure process transparency, results replicability and an appropriate update of results if any related data is generated in future studies [14].

4.2 Methodology

4.2.1 Systematic Mapping Methodology

Because there is no current standard to perform systematic mapping in the social impact assessment field, the methodology presented in this study is based on the work of James et al. [27], which has been adapted to the field of social impact assessment. Due to the existing similarities between systematic mapping and systematic reviews, this study incorporates elements from the work of Biolchini, et al. [98], Mulrow [99], Petti, et al. [24], Zamagni, et al. [28] and Zumsteg, et al. [14]. The methodology consists of a series of sequential steps that are explained in more detail in the following subsections. This evidence synthesis method was selected over the systematic review for numerous reasons. First, the objective of the research question is to describe the state of knowledge of the social impact assessment field. Answering this research question requires researching broad topics that are not suited for systematic reviews, which are usually used for more focused topics. Second, the articles included in the search database are from numerous sources, including published articles, company reports and grey literature. The systematic mapping is better accommodating for the heterogeneous information sources considered in the study relative to the systematic review. Third, the synthesis of the selected articles follows a meta-data approach that aims at identifying trends in the literature, research gaps and clusters, but no quantitative or qualitative synthesis of the results is to be presented, as is commonly done in a systematic review.

4.2.2 Review Team

The review team for performing the systematic map consists of two members. The objective, scope, research question as well as the inclusion criteria, were developed by both team members. One of the team members performed the literature search and article screening. This same person performed the coding of the results to be used for creating the visualization of the results. The other team member served as a manager to ensure quality assurance along the complete process. The review team also discussed and agreed upon selecting the systematic map over the systematic review method based on the objectives and characteristics of the study.

4.2.3 Systematic Map Research Question and Objective

The objective of the systematic map in this study is to describe the current state of knowledge of the social impact assessment field with respect to the methods available to perform such studies. The research question to be answered is the following: "*What are* *the current methods available to perform social impact assessments, and how have they been implemented?*" In order to better answer and organize the results, the main research question has been divided into the following sub-questions:

- How many case studies were published between 2009 and 2019?
- What are the areas of application of social impact assessments?
- How are these applications being carried out?
- What are the subjects being assessed for social impacts?
- Which are the geographical areas being considered in social impact assessment studies?
- What are the main challenges for each of these social impact assessment methods?

4.2.4 Keywords and Source Databases

A literature search was selected as the method to search for information. The systematic map focused mostly on academic literature from academic peer-reviewed journals, academic conference proceedings, and to a lesser extent, grey literature. Book chapters and books were excluded from the database because the information is presented less concisely relative to scholarly articles. The results from this study should motivate more focused studies, such as systematic reviews, and those should include book chapters and books in their analysis, as those aim to have a more detailed understanding of the topics under study. The main search database was SCOPUS, supplemented by Google Scholar and the Google search engine. The search string used in the systematic map consisted of the following two areas (shown in bold below), with their respective synonyms:

1. Social Impact Assessment

   a. Social Life Cycle Assessment OR Social Life Cycle Sustainability OR Social Impact Method OR Social Innovation OR Social Assessment or Social Sustainability
2. Product Development
   a. Product Innovation OR Product Design OR Concurrent Engineering OR Engineering Design

4.2.5 Inclusion and Exclusion Criteria

An important aim of this study was to gather evidence related to social impact assessment regardless of the discipline. Instead of performing a focused literature search and restricting the articles only to those in the Engineering or Mathematics fields for example, the research team wanted to gather as much evidence as possible, regardless of the field of origin. In addition, no restriction was placed with regards to the country of origin of the study or the industry of application.

The research team knew a priori about the breadth of applications being covered by social impact assessments, and the goal was to obtain knowledge from heterogeneous sources to gather a wide range of evidence and topics. The only two major inclusion restrictions were that the articles were written in the English language, and that they either provide a social impact assessment method or provide a review of other social impact assessment studies.

4.2.6 Screening for Evidence

As with systematic reviews, the systematic map follows a structured and objective methodology for screening the literature information. The following procedure was carried out to determine if the article would be selected as part of the systematic map:

1. Read the article title and keywords
2. Read the abstract
3. Read the introduction and conclusion
4. Read the full text

Each step was performed in a sequential manner, continuing to the next step if the previous step did not allow the author to determine whether the articles should be selected or not. By following this procedure, a total of 81 journal articles were selected, of which 49 included a case study application. An additional number of grey literature documents were selected based on references found in the journal articles themselves.

4.2.7 Coding

Coding is the process of assigning categories to generic and detailed information of the selected articles. It organizes, categorizes and describes the records included in the systematic map, allowing users to organize the results by a particular topic or a descriptor of the articles [27,100]. For the present study, coding was performed by a single team member, and then verified by the team manager. Two coding approaches were performed in this study. A general coding consisting of the article author information, date of publication, journal of publication and the industry sector based on the 2017 North

American Industry Classification System (NAICS) [101]. For articles with a case study application, a more detailed coding procedure was followed. In addition to the previously mentioned generic coding, the more detailed coding included the case study timing, the scope of the case study, the method applied, the geographic information of the researchers performing the case study and of where the case study was performed, the type of indicators used in the study, the type of data source, and finally the application of the case study to the product development process. The coding variables used for the meta-data analysis are summarized in Table 7 and Table 8.

Table 7: Nomenclature of generic coding.

Coding Variable	Information Being Extracted
Full reference	Authors, article title, journal of publication
Publication type	Academic journal, roundtable, report
Industry sector	Industry classification based on the 2017 North American Industry Classification System (NAICS) [101]

Table 8: Nomenclature of detailed coding.

Coding Variable	Information Being Extracted
Timing	Pre or post study timing
Continent of researcher	Continent of researchers conducting the study
Continent of case study	Continent where case study is being performed
Indicator type	Quantitative, semi-quantitative or qualitative indicators
Data source	Primary or secondary data source
Application to product development	Applicability of method to the product development process

4.2.8 Research Synthesis Methodology (Meta-Data)

There are numerous approaches to synthesizing the results from a systematic map. As stated by Zumsteg, et al. [14], “approaches range from qualitative work, such as grouping and summarizing of expert opinions, to quantitative synthesis, in which the published data are adjusted to a common value or other statistical methods are utilized as part of a meta-analysis". Meta-analysis is meant to analyze a large collection of data from individual studies with the purpose of integrating its findings [28]. The meta-data synthesis consisted of two parts. The first part consisted of summarizing the article information using the generic and detailed coding variables already defined. This information was used to create an electronic database that summarizes the information of the selected articles. The second part of the study consisted of a qualitative integration of the articles that included summarizing the challenges of performing social impact assessments identified in individual articles.

4.2.9 Expected limitations of the Systematic Map

Instead of focusing on small discipline subsets, the research team wanted to explore social impact assessments across many disciplines, which is one of the reasons why a systematic map was chosen as the method to perform the evidence synthesis, rather than the systematic review. Although the research team wants the results to be as generalizable as possible, the breadth of applications of social impact assessments limit this applicability. The results and discussion section only apply to the samples analyzed in this study.

4.3 Results

The systematic mapping allows the identification of the current methods that are available for researchers to perform their assessments, their advantages and disadvantages, and the challenges that users may face when using the methods. A total of 81 articles were selected, of which 49 had a case study application. The results are organized in the following manner. Section 4.3.1 provides a summary of the articles selected using the systematic map procedure. The articles are classified based on the generic coding presented in Table 7 of the Materials and Methods section. Section 4.3.2 provides a summary of any industry peer-reviewed methods available to perform social impact assessments. Industry peer-reviewed methods involve roundtables and collaborations from industry experts, academic and university centers, and even representatives from government agencies in some cases. Such methods are briefly explained, along with a summary table that presents challenges related to their application. Section 4.3.3 provides a summary of the identified challenges for the application of social impact assessments. The identified set of 12 challenges are tabulated, along with the articles in which they are mentioned.

4.3.1 Systematic Mapping Results

4.3.1.1 Number of Articles Per Year

Figure 3 shows a plot of the number of articles with respect to their year of publication. As previously mentioned, the recent increase in the number of social impact assessments is attributed to two publications. The first one is the 2009 United Nations Environmental Program (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) guidelines [2] for performing social impact assessments. The starting year of 2009 for the inclusion of articles in the systematic map is based upon the year of publication of such guidelines. At this point in time, the field was lacking a major systematic set of guidelines on how to perform a social impact assessment. The UNEP/SETAC guidelines provided a lifecycle-based framework grounded in stakeholder theory.

The guidelines also cover how to collect data and to assess the quality of the data being used for the studies. Although the contribution from the guidelines was significant, there were still a lot of open questions, especially in the selection of the impact subcategories and indicators. In this research, impact indicators are defined as quantifiable metrics that are used to track social impacts based on measurement [102]. Some common examples of indicators are income distribution, occupation injuries and deaths, and access to potable drinking water [44]. The 2013 Methodological Sheets, also from the UNEP/SETAC group, provided additional direction for performing social impact assessments [103]. The publication of these two sets of guidelines resulted in a significant increase in the number of case studies and applications of the guidelines for performing social impact assessments.

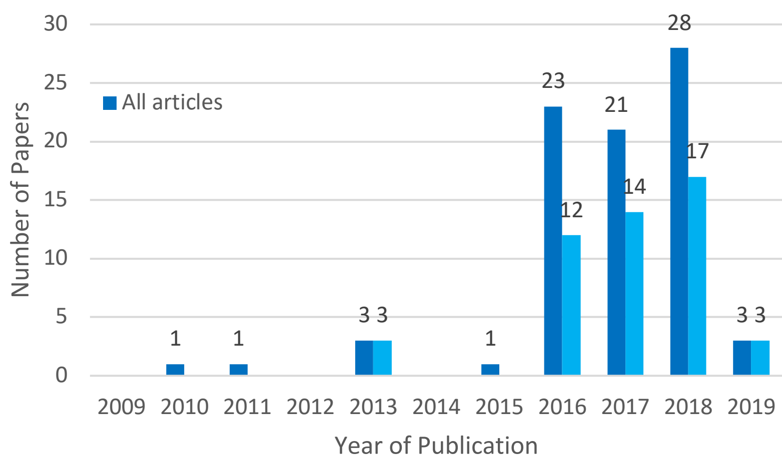


Figure 3: Distribution of articles (*n* = 81) and case studies (*n* = 49) with respect to year of publication.

4.3.1.2 Distribution of Articles in Scientific Journals

Figure 4 shows the top 4 scientific journals in which the selected articles were published. The results show that a combined 51% of the selected articles were published in either the International Journal of Life Cycle Assessment or the Journal of Cleaner

Production. The high number of articles published in the International Journal of Life Cycle Assessment results from the fact that most of the articles follow a life cycle approach when performing their analysis. The high number of articles published in the Journal of Cleaner Production highlights the fact that many social impact assessment studies are complementary to environmental impact studies. In addition, some authors incorporate environmental impacts as part of their social impact assessment analysis.

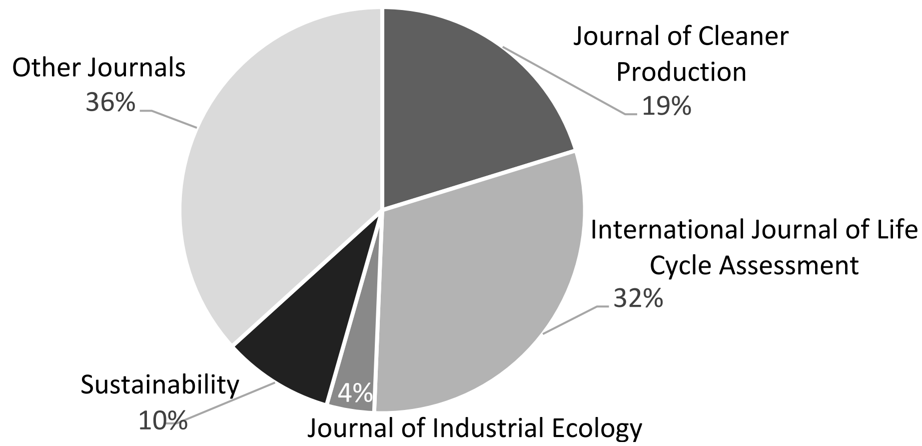


Figure 4: Distribution of scientific journals in which the selected articles were published (*n* = 81).

4.3.1.3 Distribution of Industry Sector of Application

Figure 5 shows the distribution of the selected articles with respect to their industry type. The 2017 North American Industry Classification System (NAICS) was used as a reference for industry classification of the articles [101]. The Agriculture, Forestry, Fishing and Hunting and the Manufacturing industries, are the most represented, contributing to 36% of the total articles. The Utilities, the Professional, Scientific and Technical Services and the Mining, Quarrying, Oil, and Gas Extraction industries, collectively make up an additional 26% of the industrial applications. It is interesting to see that a lot of these industries involve a high environmental impact, which highlights the fact that the social impact assessment studies usually evolve as an extension of environmental assessment studies [24].

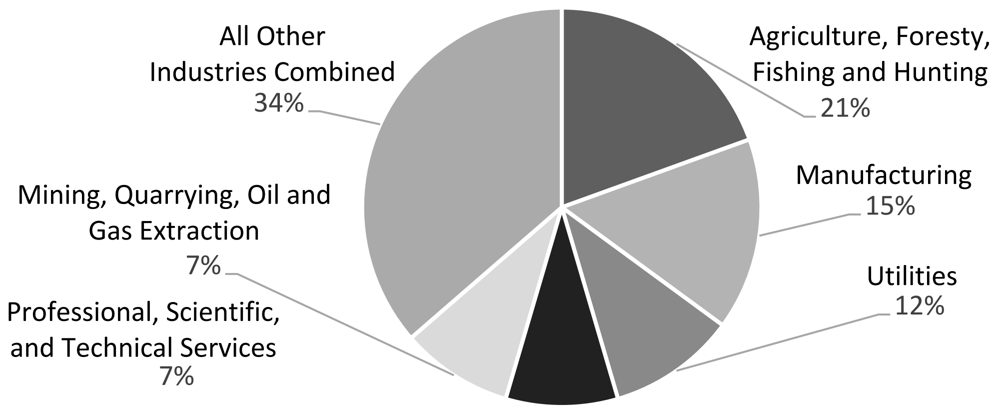


Figure 5: Distribution of articles by industry of application (*n* = 81).

4.3.1.4 Case Study Distribution of Industry Sector of Application

Out of the 81 articles selected using the systematic mapping, 49 have a case study application. Figure 6 shows the distribution of the case studies with respect to their industry classification, based on the NAICS [101]. Similar to all of the articles, the Agriculture, Forestry, Fishing and Hunting sector has the highest representation with 18%. The Manufacturing and Utilities sectors have a similar representation. The top 3 industries collectively represent 48% of the selected case studies. Contrasted with the previous classification, there is an increased representation for the Transportation and Warehousing industry sector, which results from the number of case studies involved with the transportation sector.

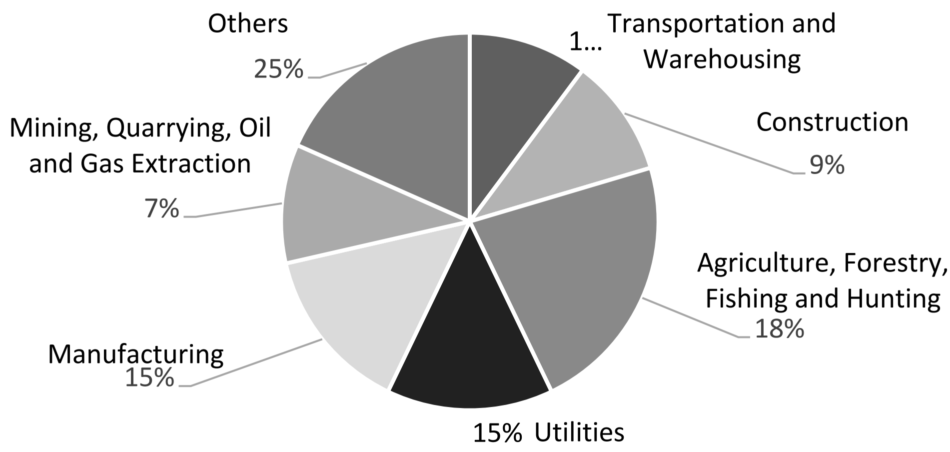


Figure 6: Distribution of case studies by industry classification (*n* = 49).

4.3.1.5 Case Study Timing

Figure 7 shows the timing of the application of the case study shown in the article. As expected, most of the social impact assessments are performed post-implementation, meaning that the product or system being evaluated is already in place. This result was expected, because one of the biggest challenges when performing a social impact assessment is the availability of data. Different from environmental and economic impact assessments, the use of regional data is very important when performing social impact assessments. Due to the globalized nature of current products and services, it can be a big challenge to gather the necessary social data from all companies involved in the different life cycle stages of the products or systems. This procedure is even more complicated at pre-implementation stages, during which the authors do not fully know the companies that will be involved in the product or system. One of the goals of the social impact assessment field is to increase the number of applications at the pre-implementation stage, as this will result in decisions that increase the amount of positive social impacts from products and services. This would be a pro-active approach rather than the currently more common reactive approach.

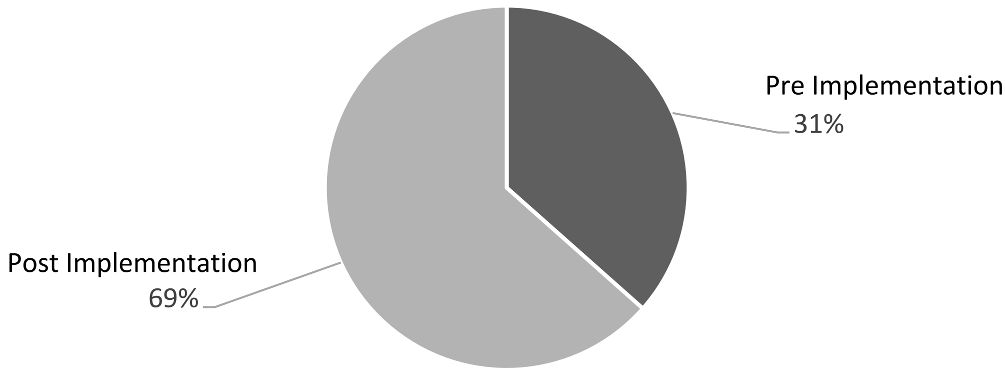


Figure 7: Distribution of the timing of case study performance within articles (*n* = 49).

4.3.1.6 Case Study Methodology

Figure 8 shows that 88% of the case studies applied a Social Lifecycle Assessment (S-LCA) method when performing the social impact assessment. This shows the fact that most practitioners prefer to follow an LCA approach, which has been the dominant approach to follow when performing environmental assessments. Naturally, if a practitioner performs a social impact assessment as an extension of an environmental assessment, an LCA approach would be followed. Out of the LCA percentage, 44% of the studies follow the 2009 UNEP/SETAC guidelines, showing the significance that publication has had on the field. The fact that only 12% of the case studies do not follow an LCA approach shows the difficulty of performing social impact assessments.

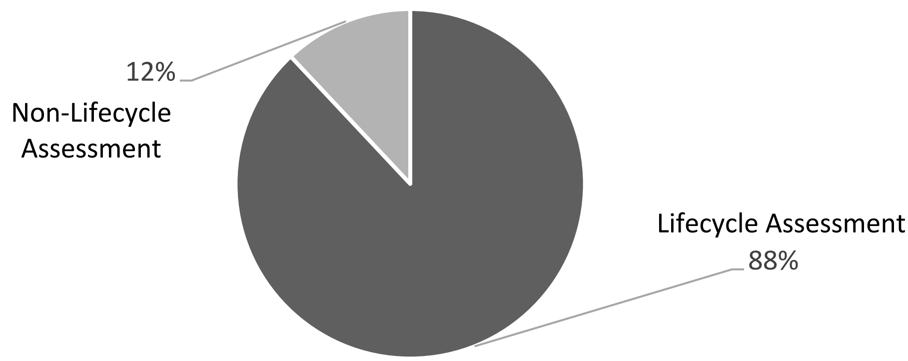


Figure 8: Distribution of the methods applied in the case study (*n* = 49).

4.3.1.7 Case Study Continent of Researcher and Continent of Application

Figure 9 and Figure 10 show the continent of origin of the researchers performing the case studies, and the continent where the case study is being performed, respectively. The American continent has been subdivided into North, Central and South America. This subdivision is based upon two aspects: the significant geographic size of each subdivision, and the significant socio-economic differences that exist among each of them. Figure 10 shows Europe as the leading continent with respect to performing social impact assessment studies, followed by Asia and North America. These three locations combined account for 81% of all of the case studies. As mentioned in [24], it is interesting to see that most of the case studies are performed by Europe, a continent that has a relatively high quality of living. Numerous reasons are cited for this. Europe has a high concentration of university centers that focus on social impact assessments. In addition, Europe has a well-developed social data infrastructure, which is useful when performing social impact assessments. Continents with less developed economies usually encounter more challenges with regard to the availability of social databases and their data collection infrastructure [26]. Social impact assessment practitioners in the European Union (EU) and the European Economic

Area (EEA) should be aware of the changes to personal data management instituted by the European Commission of policies, information and services through the General Data Protection Regulation (GDPR) of April 2016 [104]. The new regulation has been active since 25 May 2018, and it pertains to the use of personal data such as religious beliefs, sexual orientation or any type of data that would allow the identification of the individual [44].

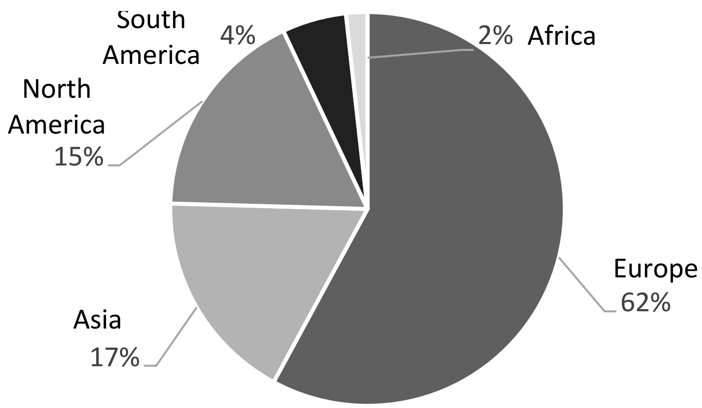


Figure 9: Distribution of the native continent of researcher performing the case studies (*n* = 49).

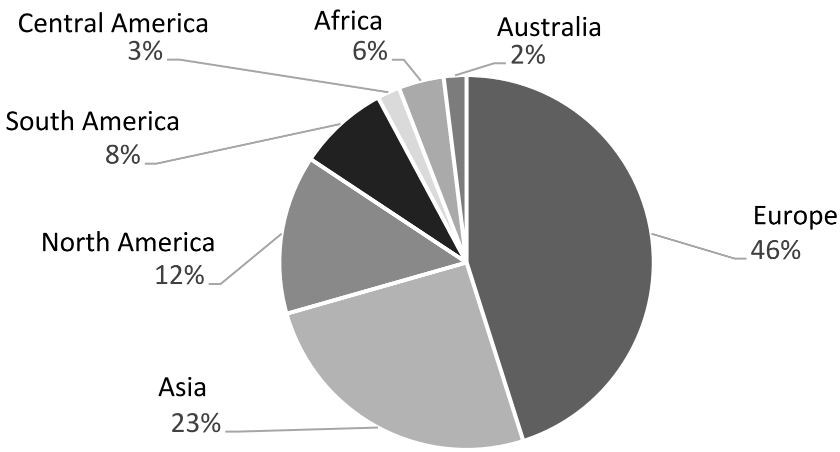


Figure 10: Distribution of continent considered in case studies (*n* = 49).

Figure 10 shows a similar trend to Figure 9, with the main difference being the fact that there are additional geographical locations considered where the case studies are performed. An increase in the African Continent is seen and the appearance of Central America, which was not at all present in Figure 9. The hope is that, as the social impact assessment field progresses as the field matures, the distributions shown in Figure 9 and Figure 10 will be more equally spread on a global scale. Figure 11 shows a visual mapping between the country of the researcher performing the study (red solid dot) and the location of the case study itself (blue solid dot). It shows a global distribution among the case studies, and also how most of the studies originate at the United States, China and from within European countries.

Figure 11: Mapping of the country of the researcher to the country of the case study. Red dots (●) indicate the locations of the researcher and blue (●) indicates the locations of case studies. Shading levels refer to number of studies originated at that particular country.

4.3.1.8 Industry Sector Application by Continent

Table 9 shows the distribution of the industry sector by continent based on the 49 case studies analyzed. This information allows us to determine which industry sectors are being studied in which countries. Europe has the highest representation of all continents with 59.2% of all industry sectors, while America and Asia both show a similar representation of 18.4% and the remaining 4.1% belongs to Africa. The higher representation of Europe was also found in a previous systematic literature review performed by Petti, et al. [24]. Future research is encouraged in Africa, America and Asia with the hope of achieving an equal representation of all industry sectors at a global scale.

Table 9: Industry sector share by continent values.

Industry Sector	Africa	America	Asia	Europe
Administrative and Support and Waste Management and Remediation Services	0%	20%	0%	80%
Agriculture, Forestry, Fishing and Hunting, Transportation and Warehousing	0%	0%	0%	100%
Construction	0%	14%	43%	43%
Management of Companies and Enterprises	17%	33%	17%	33%
Manufacturing	11%	22%	22%	44%
Mining, Quarrying, Oil and Gas Extraction	0%	0%	60%	40%
Other services	0%	50%	0%	50%
Professional, Scientific, and Technical Services	0%	0%	0%	100%
Transportation and Warehousing	0%	25%	0%	75%
Utilities	0%	13%	0%	88%
% among all industry sectors	4.1%	18.4%	18.4%	59.2%

4.3.2 Industry Peer-Reviewed Frameworks and Methods for Performing Social Impact Assessments

This section provides a summarized description of the identified industry peer-reviewed frameworks. A brief description of each framework is presented, along with a summary of its applicability and challenges. Table 10 provides a summary of the frameworks and methods presented in this section along with notable challenges for each.

Table 10: Summary of industry peer-reviewed frameworks for performing social impact assessments.

Name	Notable Challenges
Social Lifecycle Assessment (S-LCA)	Lack of standard for indicator list, normalization of results and results reporting Data requirements are high
2018 Product social impact assessment (PSIA) from the Roundtable of Social Metrics	No support for aggregation and weighting steps Not suitable for quick screening studies Difficulty to access data needed for analysis
2009 UNEP/SETAC Guidelines	Not suitable for quick screening studies No guidance for the use phase of the lifecycle Data requirements are high
2013 United Nations Environment Program/Society of Environmental Toxicology and Chemistry (UNEP/SETAC) Methodological Sheets	Lack of guidance on how to perform the social assessment
Prospective Sustainability Assessment of Technologies (PROSUITE)	Micro-assessment tool is only applicable to chemical products Not suitable for screening analysis
Life Cycle Attribute Assessment (LCAA)	No guidance on the selection of indicators Results depend heavily on the indicators selected for the analysis
WBCSD Social Lifecycle Metrics for Chemical Products Guideline	Only applicable to chemical products Use of 5-point scale for results might be misleading
Poverty and Social Impact Analysis (PSIA)	Interaction between policies are not captured Data and information constraints, analytical constraints and time constraints
Socio-Economic Impact Assessment (SEIA)	Level of detail of analysis is determined by the level of detail of the environmental assessment System boundary definition is the same as the environmental assessment

4.3.2.1 Social Lifecycle Assessment (S-LCA)

A Social Lifecycle Assessment (S-LCA) is a method that aims to assess the social and socio-economic aspects of products along with their positive and negative impacts throughout their lifecycle, encompassing the extraction and processing of raw materials, manufacturing, distribution, use, re-use, maintenance, recycling and their final disposal [10,24]. Research into S-LCA started in the mid-1990s and developed significantly from 2005 [105]. The S-LCA framework can be seen as an extension of an environmental impact assessment, meaning that it has a similar four step structure as stated in the LCA standard ISO 14040: (1) Definition of goal and scope, (2) lifecycle inventory analysis, (3) impact assessment analysis and (4) interpretation of results [10]. The goal of the S-LCA framework is to assess all of the social impacts that a product or service causes for its stakeholders throughout the complete lifecycle of the product, relative to the system of reference defined. Social impacts are understood as the positive and negative consequences on the stakeholders involved in the lifecycle. As seen from the systematic mapping, the S-LCA framework is the one adopted by the majority of authors. Although there has been a significant increase in the number of researchers applying this method, it still faces many challenges, especially in the selection of impact categories and indicators. As a result, a significant number of authors follow the framework in their studies, but the indicators and impact categories are highly varied.

The literature also exhibits a classification among S-LCA studies: Type I and Type II S-LCA studies. This classification is based upon the fact that Type II studies use a causality-based characterization, meaning that there are causal relationships between the input inventory data and the midpoint and endpoint level impacts [48]. Type I S-LCA studies use a Performance Reference Point (PRP) approach to assess the impact data, in which the inventory values are compared to established nominal reference values to determine the magnitude of the impacts, and whether the impacts are positive or negative. The results are aggregated into subcategories according to the stakeholder's interest, and the aggregation is performed using a scoring system [48,106].

4.3.2.2 Product Social Impact Assessment (PSIA) from the Roundtable of Social Metrics

The Handbook for Product Social Impact Assessment (PSIA) [6] describes a consensus-based method to assess the positive and negative social impacts of products and services based on the following four stakeholder groups: Workers, local communities, small-scale entrepreneurs and users. The method focuses on assessing the social impacts of products and services, rather than on the impact of the company as a whole. The handbook closely follows the structure of an environmental LCA, as it is aimed to be used by practitioners that want to extend their environmental assessment with the social aspects of the company's products. The roundtable was initiated because the companies recognized the need for a social impact assessment method that is relevant for business. Some of the limitations of PSIA have to do with the amount of data needed to perform the analysis. Also, the results are presented using a 5-point scale, which may be an oversimplification for real-life scenarios. The method does not provide support for performing the aggregation and weighting steps in an impact assessment.

4.3.2.3 UNEP/SETAC Guidelines

The guidelines for a social lifecycle assessment of products [10] provide a set of social and socio-economic LCA-based guidelines to complement the Environmental and Life Cycle costing assessments, contributing to the full assessment of goods and services within the context of sustainable development. The framework follows the structure of the ISO 14040 and ISO 14044 standards for performing environmental LCA. The guidelines propose a twofold classification of social impacts: By stakeholder categories and by impact categories. On the basis of the most current and state of the art methodological developments, this document formulates guidelines on how to assess a product based on social and socio-economic indicators.

The guidelines are based on stakeholder theory, where impact categories are assigned to each stakeholder category, and inventory indicators and subcategories are assigned to each of those impact categories. The framework presented in the guidelines is based on subcategories, which are socially significant themes or attributes that are classified according to the stakeholder and impact categories; the subcategories are assessed by the use of inventory indicators.

Although their contribution of the guidelines to the social impact assessment field has been significant, they present some significant challenges to the practitioners. The guidelines provide a general framework for performing a social impact assessment, including a set of stakeholders and indicators for each of the social impact categories. However, they are not clear on how to perform an objective selection of the stakeholders and indicators used in the analysis, and on how to normalize or aggregate the results.

Another drawback of this method is that it is not developed enough to assess the use phase of the lifecycle.

4.3.2.4 UNEP/SETAC Methodological Sheets

The Methodological Sheets [22] are intended to be used as a complement to the 2009 guidelines when performing the S-LCA. The sheets have been developed recognizing that data collection is the most challenging step when performing a social impact assessment study. Because the sheets are meant to serve as a complement to the 2009 UNEP/SETAC guidelines, these are organized based on the stakeholder categories of workers, local community, society, consumers and value chain actors, under which each corresponding subcategory identified in the guideline is further elaborated. For each stakeholder category, the sheets provide a detailed definition of the stakeholder category, policy relevance of the category, relevant international conventions and agreements, examples of inventory indicators, units of measurements and data sources for generic and specific data analysis. Although the sheets provide a vast amount of data for each of stakeholder category, there is still a lack of guidance on how to perform subsequent steps of the assessments.

4.3.2.5 Prospective Sustainability Assessment of Technologies (PROSUITE)

The Prospective Sustainability Assessment of Technologies (Prosuite) [107] aims to deliver a broad life cycle assessment (LCA) framework for the sustainability assessment of existing and new technologies, taking into account the three pillars of sustainability: Economic, environmental and social. The framework is applicable to the evaluation of different technology alternatives and supports policy decision making and future company decisions. It relies on the evaluation of a prospective technology with respect to a reference technology scenario. It is included in this document, as it is one of the few methods that exist to assess prospective technologies. The method has a micro-assessment tool that is intended to be used to perform a social impact analysis regarding the "prosperity" category in the analysis.

However, the micro-assessment tool is only applicable for chemical plants; the prosperity analysis must be performed manually for other products and services. Another limitation of the PROSUITE method is that the analysis takes a significant amount of time, which means that it is not suitable for performing a screening or low detail analysis, unless some parts of the analysis are omitted.

4.3.2.6 Life Cycle Attribute Assessment (LCAA)

The Life Cycle Attribute Assessment (LCAA) [108] method summarizes attributes of processes along a product's life cycle or company supply chain by means of certification of process attributes. The method builds on the theoretical structure of LCA to construct a supply chain model and aims to enable local, site-specific evaluation results (i.e., SA 8000, ISO 14001, Fair Trade Certification) to be integrated into LCA. The method provides a link between the LCA and Corporate Social Responsibility (CSR) methods [109], by determining what percentage of a product's supply chain has a particular attribute. The method does not provide any guidance for the selection of indicators when performing the attribute calculation, meaning that the indicators used depend heavily on the user.

4.3.2.7 WBCSD Social Lifecycle Metrics for Chemical Products Guideline

The Social Lifecycle Metrics for Chemical Products Guideline provides guidance and social lifecycle metrics that enable companies to assess and report on the social impacts of chemical products within the full value chain, by means of a life cycle approach [110]. This method is inspired mainly by the 2009 UNEP/SETAC Guidelines [10] and the 2014 Handbook for Product social impact assessment [6]. The method relies on 25 selected social topics that are divided into two groups: 11 mandatory social topics, and 14 non-mandatory social topics. The results are presented on a 5-level reference scale from −2 (unacceptable) to +2 (outstanding) via 0 (standard compliance). The framework was included in this summary, as it is applicable to products from the chemical industry specifically.

However, the method still presents some significant challenges to the user. The use of a 5-point scale might be misleading when reporting the final results. Also, the analysis is very elaborate and data-intensive, meaning that it is not suitable for performing screening or low-detail studies.

4.3.2.8 Poverty and Social Impact Analysis (PSIA)

Poverty and Social Impact Analysis (PSIA) involves the analysis of the distributional impact of policy reforms on the well-being of different stakeholder groups, with a particular focus on the poor and vulnerable [111]. The framework aims at understanding the impact of policy changes by evaluating policy impacts individually to understand the overall effect of a group of reforms. Now that poverty has been recognized as a multidimensional issue, social indicators are now used in its analysis, in addition to economic indicators.

PSIA assumes that policy impacts will affect the welfare of communities through five channels: Employment, prices (production, consumption, and wages), access to goods and services, assets and transfers and taxes. It is expected that single policy reform will affect more than one channel. One of the main challenges with performing PSIA is understanding long-term policy effects based on short-term information, because policy impacts take time. In addition, the effects of policy impacts will depend upon the stakeholders, as each has different circumstances, but are impacted by the same policy reform. Because policy reforms are evaluated individually, the interaction effects between the policies are not captured.

4.3.2.9 Socio-Economic Impact Assessment (SEIA)

Socio-Economic Impact Assessment (SEIA) is a systematic method used during environmental impact assessment to identify and evaluate the potential socio-economic and cultural impacts of a proposed development on the lives and circumstances of people, their families and their communities [112]. Impacts are defined as changes caused directly or indirectly by industrial development activities. SEIA tends to focus on avoiding detrimental social impacts caused by industrial development activities, and also to plan for maximizing the benefits of such activities. The method is a complement to performing an environmental impact analysis, and it focuses on identifying, assessing, mitigating and monitoring the potential socio-economic impacts of a proposed development.

4.3.3 Determination of Challenges from Systematic Map

The systematic map protocol enables a detailed understanding of current social impact assessment methods and can also reveal gaps that are present in the field. The determination of such gaps allows the researcher to determine important aspects of the research, such as the relevant areas of the contribution of the research or the main barriers that are preventing the field from advancing. For the social impact assessment field, a number of challenges were identified from the selected articles. Table 11 provides a summary of the challenges identified in the social impact assessment field, along with the reference articles in which each of the challenges are mentioned.

Table 11: Summary of challenges when performing social impact assessments.

Challenge	Explanation	Related Articles
1	Determination of what social impacts to consider and how to quantify them	[1,13,42]
2	Uncertainty with indicator selection, normalization, aggregation, and weighting	[43–52]
3	Determination of whether a functional unit should be used	[11,52–56]
4	Determination of minimum criteria to be satisfied during data collection efforts	[34,50,57]
5	Allocation of social impacts into different categories	[50,57–59]
6	Connection of social impacts with products rather than with the conduct of companies producing the products	[60,61]
7	Definition of "social well-being" used in the analysis	[45,55,62–65]
8	Selection of a preferred method to perform the social impact assessments	[4,31,52,60,66]
9	Definition of the system boundaries	[13,32,54,58,67,68]
10	Selection of global or location specific data	[51,57,60,69]
11	Selection of scoring scales for reporting the results	[34,39,51,61,70–72]
12	Selection of stakeholders relevant to the study	[39,40,57,58]

4.4 Analysis of Results

4.4.1 Discussion of Selected Articles

A summary of articles that used literature reviews to investigate challenges and future research direction for social impact assessments is shown in Table 12. As with the rest of the selected articles, most of these focus their literature review on the S-LCA framework. The majority of these studies focus on the methodological weaknesses of S-LCA [24], such as the selection of impact criteria and indicators [19,25,105], identification of the system boundaries [113], the selection of inventory data, characterization and the weighting method used [106]. Two articles focus on the use of a systematic review to determine future research areas of research in S-LCA [114,115].

Table 12: Summary of previous systematic review articles.

Reference	Year	Issue Investigated
[105]	2018	Selection of impact criteria and indicators
[114]	2018	Use of automatic text analysis to determine state of the art and future research direction
[113]	2018	Identification of the system boundaries and areas of needed developments
[25]	2017	Identification of issues with indicators across industries. Authors synthesize a list of indicators as a step towards standardization.
[24]	2018	Weaknesses of Social Lifecycle Assessment (S-LCA) by means of case study analysis
[19]	2018	Identifications of social impacts of products
[106]	2018	Exploration of type I S-LCA methods with a focus on inventory data, aggregation, characterization and weighting methods
[115]	2018	Analysis of the main issues affecting S-LCA with a focus on the automotive sector

Because of its wide implementation, methodological issues with the LCA framework have been highlighted by numerous authors outside of the social impact assessment field [28,116,117]. This is why a lot of the challenges mentioned by the authors are also present in environmental LCAs. Based on the systematic map results, the majority of authors use a social impact assessment framework that is LCA-based. It should then be no surprise that a lot of these challenges are mentioned by the authors when performing social impact assessments using S-LCA. Although most articles follow an LCA approach, the framework being implemented is modified based on the application being analyzed. This becomes a significant challenge when attempting to propose a standard framework that is appropriate for most applications. Among the LCA studies, the 2009 UNEP/SETAC guidelines had a strong presence, where 44% of the case studies cite them as a source of information with regards to the stakeholder groups, impact categories and indicators. Another important observation regarding LCA studies is that 79% performed a “cradle to gate” analysis while 21% performed a “cradle to grave” analysis, which is expected, due to the higher level of complexity present in the “cradle to grave” analysis.

The case studies were evaluated with regards of the scope of the study, i.e., the purpose of performing the social impact assessment. The case studies were classified according to the following categories adopted from the work of Kjaer, et al. [118]: Comparison, informative or enhancement scope. Table 13 shows the question being addressed by each of the study scopes. The comparison scope aims to evaluate the social impacts among different alternatives. Thirty-six percent (36%) of the case studies had a comparison scope. The informative scope assesses the social impacts resulting from the implementation of the system being studied. Fifty-six percent (56%) of the case studies had an informative scope. The enhancement scope aims to determine how the system implemented can be enhanced. Only 8% of the case studies had an enhancement scope. These results show that most social impact assessments are focused on having an understanding of the social impacts of the system and on how the selection of different alternatives affects these impacts.

Table 13: Study scopes identified in case studies.

Study Scope	Question Addressed
Comparison	What are the social impacts among different alternatives?
Informative	What are the social impacts resulting from the introduction of the system?
Enhancement	What are the social impacts of the system, and how can it be enhanced?

Although access to data is recognized as one of the most difficult aspects of performing a social impact assessment, 96% of the case studies relied upon data for performing their analysis, while only 4% relied on the use of modeling. Among those that used data, 50% used a combination of primary and secondary data sources, 30% used primary data only, and 20% used secondary data only. Regarding the type of indicator used in the case studies, 56% use quantitative indicators, 24% use qualitative indicators and 20% use semi-quantitative indicators.

Table 14 shows a summary of the databases used in the case studies. The databases were classified based on the following three categories: Global or International Agreements, Standards or Handbooks, Sustainability Frameworks and Country or Economic Sector Guidelines. The number of databases highlights the difficulty in achieving a generalization of data among different social impact studies, as there is usually no agreement among the data reporting infrastructure within them. This is one of the biggest roadblocks towards achieving standardization among the social impact assessment framework. Before deciding whether or not standardization is the best approach, one must carefully balance the risk of losing local context with the risk of achieving a standard method.

Table 14: Information databases used in the case studies. (Where ISO refers to the International Organization for Standardization).

Category	Database Name
Global or International Agreements, Standards or Handbooks	• World Mineral Statistics Datasets • Social Hotspot Database • Global Reporting Initiatives (GRI) • ISO 26000 • ISO 19712-1: 2008 • ISO 14040 • International Reference Life Cycle Data (ILCD) Handbook • Intergovernmental Panel on Climate Change (IPCC) Organization for Economic Development • International Labor Organization • GRI's G4 sustainability reporting guidelines • United Nations Development Program • International Standard Industrial Classification • Institute for Employment Research (IAB)
Sustainability Frameworks	• Social progress Index • Sustainable Society Index • 2009 UNEP/SETAC Guidelines • Sustainability Appraisal in Infrastructure Projects (SUSAIP) • Technical Sustainability Index (TSI) • 2011 Methodological Sheets • Sustainability Assessment of Agriculture Systems
Country or Economic Sector Guidelines	• Hong Kong Business Environment Council Limited • LIFE 2012 European Projects • Brazilian Institute of Geography and Statistics • Ministry of Labor and Employment and Ministry of Social Security • National Statistics Institute of Spain • Chinese Core Life Cycle Database • Organization for Economic Cooperation and Development • US Executive Order 13514 • US Advanced Manufacturing Cluster • US Bureau of Economic Analysis Data • North American Industry Classification System (NAICS)

Table 15 shows a summary of the articles based on the type of impacts being analyzed in each of them. The majority of articles (75%) focus on evaluating socioeconomic impacts, which is expected, since most of the articles apply the UNEP/SETAC Guidelines [10] framework, in which socioeconomic impacts are the focus. Eleven percent (11%) of articles perform the analysis based on the three-dimensional sustainability approach, which states that sustainability is composed of an economic, environmental and social dimension. A combined social and environmental focus was the least common in the selected articles, with only a 5% share. Nine percent (9%) of the articles were classified as using a "Novel Approach", meaning that the authors present a framework that is not based on the typical impact assessment approach that is presented on the UNEP/SETAC guidelines. The authors adopt methodologies from other disciplines to perform the sustainability evaluation. Reitinger et al. [119] use the capabilities approach from philosophy to define the impact categories used in their analysis. Bianchi et al. [120] propose a social evaluation of energy systems based on the following five equity definitions: Social equity, spatial equity, intergenerational equity, procedural equity and structural equity. Janker et al. [121] perform a social assessment of an agricultural system by combining Parson's social system of change and Maslow's hierarchy of needs. These are novel approaches, and they show that authors are researching methodologies outside of the typical areas to complement what is already existing in the literature.

Table 15: Summary of the approaches used for sustainability assessment.

Assessment Type	Share of Articles	Reference of Article
Socio-economic assessment	75%	[1,6,124–133,10,134–143,20,144–153,44,154,48,49,115,122,123]
Social, economic and environmental	11%	[16,46,155–158]
Novel approach	9%	[50,119–121,159]
Social and environmental	5%	[160–162][45,97,98]

4.4.2 Discussion of Identified Challenges

A total of 12 challenges were identified by reviewing the selected articles. Each of the challenges is explained in more detail in the following subsections.

4.4.2.1 Challenge #1: Determination of What Social Impacts to Consider and How to Quantify Them

Part of the issue with the determination of social impacts is that there are varying definitions of what social impacts are, and what should be considered a social impact. As pointed out in Grijalva et al. [49], “The categorizations of social performance measures presented in the literature vary greatly, resulting in non-uniform assessments in practice. There is a need for a standardized assessment tool that is generalizable and accessible to all industries”. This issue is also raised by Vanclay [9], where a review of existing lists of social impact variables are “found to be inadequate and contradictory”. Vanclay established that social impacts influence “an actual experience of an individual or community.” [9]. Another issue with social impacts is that their interpretation depends on the stakeholders themselves even when they are seen similar by analysts, which is further exacerbated by the lack of a standard code of practice when performing SIA [114].

4.4.2.2 Challenge #2: Uncertainty with Indicator Selection, Characterization or Normalization, Weighting and Aggregation

Uncertainty is present at many stages of SIA. The first step of performing any type of impact assessment is the selection of the indicators that would make up the inventory analysis. The inventory of the indicators determines what data needs to be collected to perform the assessment. Depending on the approach selected for performing the impact assessment, the practitioners would select the indicators for a predetermined list, or in other cases, the authors aim at developing their own set of indicators. As stated by Zanchi et al. [115], “a robust approach for indicators’ selection is seldom discussed and reported in a transparent way”. SIA studies use different types and numbers of social indicators, which has motivated authors to propose methods of developing social indices and indicators [123].

Once the data for each of the indicators have been selected, the next step is to normalize the values. The normalization step aims at allowing for the comparison of different impact categories that have very different numerical scales. A typical approach is the use of Performance Reference Points (PRP), which are reference values used to scale the results based on global or context-specific data values. Siebert et al. [124] raises the fact that there is no standard characterization method yet in SIA, and they propose the RESPONSA framework. The RESPONSA framework is a characterization approach that “generates context-specific PRP”, which can effectively reflect the social conditions influencing the various organizations involved in producing a specific product.

The weighting step is required to perform the aggregation of the resulting normalized values. In order to allow for the comparison of different sustainable alternatives, the results are often aggregated into a single score that represents the "sustainability level" of the design alternative being considered [107]. The weighting step assigns importance levels to the results before performing the aggregation of the results. The methods used to establish the weights vary significantly and is thus a source of uncertainty in the final results. In addition, the method used to perform the aggregation also varies among different studies, which is another source of uncertainty when comparing the results of different social assessments.

4.4.2.3 Challenge #3: Determination of Whether a Functional Unit Should Be Used

As per the Internal Standard for Environmental Life Cycle Assessment ISO 14040 [32], the functional unit is defined as "a measure of the performance outputs of the product systems". The document also explains that the functional unit provides a reference to which inputs and outputs are related, a necessary feature to ensure compatibility and comparability among different LCA studies. Different from an environmental LCA, social impact assessments deal with a higher level of qualitative indicators that are not tied to a product functional unit. The inclusion or not of a functional unit could be affected by numerous factors, such as the scope of the analysis, the relevance of the process, the product system scheme [115], and even the system boundary definition [48]. As stated in Siebert et al. [123], a review performed by Petti et al. [24] indicates that "out of 35 social LCA case studies, only 12 took a numerical unit into account, whereas 18 considered the use of a non-numerical functional unit and 5 stated no functional unit at all". In the cases in which the social assessment is performed as an extension to an environmental LCA, along with the same system boundary definitions, it is recommended to use the same functional unit for the two analyses. Other studies, such as Umair et al. [163], consider qualitative data, and they emphasize that it is not possible to express the impacts using a functional unit.

4.4.2.4 Challenge #4: Determination of Minimum Criteria to Be Satisfied during Data Collection Efforts

Data collection is a crucial component of performing social impact assessments, and it has been recognized that "data collection can benefit from improved standardization and integration with social sciences" [164]. It is often regarded as the most difficult and time intensive part of the study [110]. Data sources are divided into primary and secondary data sources. Primary data sources refer to data collected directly from the companies or institutions being studied. Secondary data sources refer to databases of collected data at the country or sector level, such as the Social Hotspot Database or the Product Social Impact Life Cycle Assessment (PSILCA) database [165]. Certain frameworks, such as the Product Social Impact Assessment (PSIA) [6], recognize the importance of data quality when collecting data and recommend the use of a data quality matrix to assess the quality of the collected data.

4.4.2.5 Challenge #5: Allocation of Social Impacts into Different Categories

The use of indicators when performing a social impact assessment involves their classification into different groupings called impact categories. Let us take as an example the PROSUITE framework for performing sustainability assessments of prospective technologies [107]. The sustainability assessment consists of an aggregated analysis of the following five impact categories: Impact on human health, impact on social well-being, impact on prosperity, impact on the natural environment and impact on exhaustible resources. To determine the impact at each category, a group of indicators is assigned to each of the impact categories. The grouping of indicators and social impacts into different impact categories can be a source of uncertainty, since there is no single, standard methodology to perform such a classification. This process is further complicated when direct links between indicators and social impacts are such a big issue in social impact assessments [164].

4.4.2.6 Challenge #6: Connection of Social Impacts with Products rather than with the Conduct of Companies Producing the Products

Evaluating the social impact of a product involves the evaluation of social conditions along the production and supply chain of a product. A practitioner performing a social assessment of a product may want to focus on the companies involved with producing such a product. In this case, the social impacts of the product would be determined by the conduct of the companies producing the product and the score they get in the set of indicators being evaluated rather than on the product itself [123]. The social assessment might not differentiate much between different products whose companies have similar social information within them [6]. This presents a significant challenge when a group of designers is evaluating the different design alternatives of a product, and the process of selecting the more socially sustainable alternative becomes a matter of the conduct of companies rather than of the technical specifications of the product itself.

4.4.2.7 Challenge #7: Definition of "Social Well-Being" Used in the Analysis

The World Health Organization (WHO) recognizes that there is no universal definition of social well-being, as it may have different connotations for different individuals [166]. Hasster et al. [142] summarize different definitions of well-being found in the literature: "For instance Keyes [167] defines social well-being as the appraisal of one's circumstance and functioning in society, while the USIP [168] defines it as an end state in which basic human needs are met and people are able to coexist peacefully in communities with opportunities for advancement". But why is the definition of social well-being so important? And how is it connected to products and services, when there is a lack of well-documented impact pathways between inputs and social impacts [106]? The definition of social well-being used in the social assessment should always be important, since the goal of performing social assessment is to minimize any detrimental impacts on stakeholders. The definition becomes especially important when using frameworks that have social well-being as part of their analysis, such as the PROSUITE framework.

4.4.2.8 Challenge #8: Selection of a Preferred Method to Perform the Social Impact Assessments

While there are many S-LCA approaches available in the literature, there is a lack of a standard method to be agreed upon, and a lack of assessment priorities [18,123]. There is not yet any common list of social impact indicators that have been agreed upon in the field [105]. Having an agreement on a global list of indicators and an assessment method will aid in the standardization of performing social assessments, and in the ability to compare the results from different studies.

4.4.2.9 Challenge #9: Definition of the System Boundaries

System boundaries define which inputs and processes are included in the social assessment. System boundaries will also define the data that needs to be gathered to perform the assessment, as it will determine the list of indicators to be used in the study. The definitions of the system boundaries found in the literature are numerous. Some studies define similar system boundaries as the environmental LCA, while others attempt to consider the full life cycle of the product, but ignore the processes that do not substantially influence the overall outcomes of the study [48]. The lack of a standardized method to define the boundaries of the analysis complicates the process of comparing results from different social assessments.

4.4.2.10 Challenge #10: Selection of Global or Location Specific Data

Different from environmental and economic impact assessments, the use of local data is essential in most social impact assessments. Some social impact assessments are performed only for screening purposes, using country or sector level data to detect areas of crucial improvement [8]. When performing a more detailed analysis, the use of local data is recommended, but there are still challenges present during the data collection stage with regards to financial and temporal resources, or even data availability. The decision to use global or local specific data is very important, and will affect the results of the social impact assessment.

4.4.2.11 Challenge #11: Selection of Scoring Scales for Reporting the Results

There is currently no general standard for interpreting the results of Performance Reference Points (PRP) social impact assessments. As stated by Siebert et al. [124] “However, a characterization approach, based on a context-specific benchmark which is easy to understand and interpret, is still missing. In general, characterization approaches provide meaning to social indicator values (i.e., the inventory data). However, there is no standardized S-LCA characterization method yet”. The variety of numerical scales used to report the results from social impact assessments are proof of the lack of a standard to report the results. As shown by Singh et al. [150] “While Hosseinijou et al. [1] have taken a 6-point scale with values ranging from 0 to 9, Foolmaun and Ramjeeawon [169] have gone for a 5-point scale with values ranging from 0 to 4. For this study, a 4-point scale having values ranging from 1 to 4 is proposed, with scoring 1, 2, 3 and 4 representing highly negative, negative, neutral and positive impact, respectively, as perceived by the individual respondents. The selection of a 4-point scale has been made to establish a reasonable balance between the ease of responding and adequate granularity in the results”. Other frameworks such as PSIA and Social Lifecycle Metrics for Chemical Products Guideline use a scale from −2 to +2 [6,110].

4.4.2.12 Challenge #12: Selection of Stakeholders Relevant to the Study

The use of stakeholder theory is significant in a number of frameworks found in the literature. Because the 2009 UNEP/SETAC was such a significant source of inspiration for social impact assessments performed after the publications, the use of stakeholder theory is very common in case studies and frameworks developed after their publication; these include, but are not limited to, WBCSD Social Lifecycle Metrics for Chemical Products Guideline, Poverty and Social Impact Analysis and the Product Social Life Cycle Assessment (PSILCA) Database [110,111,165]. The selection of stakeholders is crucial, as this determines the individuals and communities that are included within the system boundaries; in other words, it determines who will be included in the analysis. Part of the challenge when performing social impact assessments is the fact that social impacts can be more far-reaching than environmental and economic impacts, and their inclusion in the analysis needs to be balanced with the resources available to perform the study.

4.5 Conclusions

Progress in the field of social impact assessments is essential to achieve better informed decisions with respect to the topic of social impacts and social sustainability. The higher number of published articles and grey literature related to social impact assessments in recent years shows increased interest in the improvement of social aspects, resulting from product development and public policy decisions. Social impact assessments play a significant role in achieving global sustainability goals by complementing the results of environmental and economic assessment methods. In order to contribute to the development of socially sustainable practices, the purpose of this study was to develop a detailed understanding of the field by collecting and analyzing published material related to social impact assessments. Additionally, the selected articles allowed the identification of a set of fundamental challenges present when implementing social impact assessments. By means of a systematic mapping process, 81 articles were selected through an online database search, from which 49 of these had a case study application. Additionally, eight grey literature documents consisting of frameworks and roundtables were included in the process of identifying the challenges present when performing social impact assessments. The coded information has been organized in an electronic database file for the interested reader.

The selected articles and grey literature data highlighted the high variability of procedures and methods that exist in the literature to perform social impact assessments. All industry sectors (based on the 2017 NAICS) are represented at some level in the selected articles, with agriculture, manufacturing and utilities having the highest representation. LCA-based methods are the preferred choice among the selected articles, although significant variations are performed based on the characteristics of the application. Results show that most social impact assessment studies aim to evaluate the social impact of the system for informational purposes, followed by the comparison of different alternatives of the system with regard to their social impacts.

The systematic mapping also allowed for the identification of a set of recurring challenges that practitioners face when performing social impact assessments. A lot of these challenges are also seen in the field of E-LCA [116,117], and this should be no surprise, as most of the studies selected in the systematic map are based upon the S-LCA framework. It seems that in addition to the challenges already identified in E-LCA, social impact assessments add an additional level of difficulty. The 12 challenges identified by means of the systematic map should serve as a reference for future research areas to ease the implementation of social impact assessments. Although there is an increased interest from the scientific community in the field of sustainability and social impact assessments, there is still a lack of implementation by private companies of such methods. Assuming the companies are interested in understanding the social impacts of their product decisions, it might be challenging to incorporate social impact assessments into their already complicated product development process. One of the sub questions of the systematic map aimed at determining which of the articles presented a method that is applicable to the product development process. Of the selected articles, only 9% had a product development application, which shows a need for developing methods that are more applicable in this aspect. More significant is the fact that there are not any practical methods and tools to a perform sustainability assessment during the early stages of designs [16].

The learnings from the systematic mapping procedure provide the baseline information to embark the process of developing the novel SIA framework shown in chapter 5. More importantly, the challenges identified in the systematic mapping process motivated the evaluation mechanisms shown in chapter 6, 7 and 8. The goal is to enhance the efficacy of the novel SIA framework by mean of expert and student feedback and by theory testing using case study analysis.

CHAPTER 5 NOVEL SIA FRAMEWORK

5.1 Introduction

The goal of the PS stage is to develop an intervention that improves the current scenario of the SIA field. In this thesis, the proposed intervention and its main contribution is the novel SIA framework presented in this chapter. To the authors' knowledge, this is the first framework that emerges from a set of challenges identified during a result synthesis process. The framework adheres to the LCA structure presented on the ISO 14040 standard for environmental LCA, which is organized in the following stages: *goal and scope, inventory analysis, impact assessment* and *interpretation of results.* The decision of adopting the LCA structure is based on finding that 88% of the case studies reviewed during the systematic mapping procedure do so. By adopting such a structure the goal is to increase its chances of implementation by researchers and also to contribute towards a standardized methodology, which is suspected will adhere to such a structure. Also, the LCA structure allows for the integration of other LCA-based frameworks that evaluate impacts on additional dimensions, such as the economic and environmental impacts (i.e., life cycle costing (LCC) and environmental LCA (E-LCA)). The purpose of the framework is to guide a user on performing an SIA of a product system and to provide guidance on how to overcome the identified challenges. The proposed framework is presented in detail, along with individual recommendations and methodologies that are organized per each of the identified challenges. The limitations of the framework are discussed along with concluding remarks.

5.2 Methodology

The novel SIA framework is presented and its implementation is explained. The framework has two main elements: a guide that shows each of the steps and an excel document that is used to perform the assessment. The excel template organizes the analysis information per the LCA structure, and it also provides a database of indicators to use in the impact assessment stage. Sections of both documents will be used to explain the methodology and how it could be implemented.

5.2.1 Novel SIA framework

The novel SIA framework is presented below, in Table 16. The application of this framework will be demonstrated later in Chapter 8 through a case study analysis of a rooftop solar panel.

Table 16: Novel SIA Framework

Assessment Stage	Guide
Goal and Scope	A. Define the goal (objective) of the study a. Why is the study being conducted? i. Are processes, companies or both are being evaluated? b. What is the level of detail of the analysis? i. Low-detail (Screening study) ii. High-detail iii. Combination of both c. Timing of the study i. Pre or post implementation of product or technology d. Is a single product or are multiple products being analyzed? e. Define the product(s) being studied i. What is the functionality of the product? B. Define the scope of the study a. Define the spatial scale of the analysis

	i. International, National, Regional, Sector or Company b. Define the type of analysis being performed: informative, comparative or enhancement c. Define initial system boundaries i. Define product lifecycle stages considered in the analysis ii. Define initial set of stakeholders for the analysis 1. For high-detail analysis, if a new stakeholder group is created define it and explain how it does not fit into existing ones 2. Also consider adding more detailed subgroups to the main stakeholder groups provided for highly detailed analysis d. Define the functional unit i. Define a functional unit even if only qualitative indicators are used in the analysis ii. Quantification is desired to allow integration of SIA results with other methods such E-LCA and LCC e. (Optional) Determine relevance of the following definitions based on expert or stakeholder input i. Goal and Scope definition ii. Definition of system boundaries 1. Lifecycle processes selected 2. Stakeholder groups selected iii. Results from screening or low-detail study analysis
Inventory Analysis	A. Determine list of social impact categories a. Organize them by stakeholder group B. Determine list of impact indicators a. Organize the list based on the stakeholder groups, social impact categories or even lifecycle stage, just make sure that it aligns with the purpose of the analysis b. For each indicator, define the following: • Indicator type • Data collection method • Data source • Scale of data (international, national, economic sector, regional, company) C. Select data collection methods a. Define data collection efforts for primary and secondary data b. Consider financial and time resources and data availability D. Assess the quality of data using modified matrix method E. Update system boundaries based on data quality assessment results F. Update list of impact categories based on data quality assessment

	G. Update list of impact indicators based on data quality assessment H. Benchmark list of indicators using stakeholder input a. Perform this step if there is access to the stakeholders b. The analysis is a "high detail" type of analysis
Impact Assessment	A. Select the Performance Reference Point (PRP) for the quantitative and semi-quantitative indicators B. Determine calculation procedure for each indicator type a. Use suggested calculation approaches C. Calculate value of indicator based on PRP D. Determine weighting method to be used and at what level a. Determine final indicator values after weighting b. Refer to weighting methods provided in database E. Normalize impact indicator values to be between 0-1
Interpretation of Results	A. Visualize the results a. Visualize the results for each indicator b. Summarize the results for each indicator by providing the numerical value along with a narrative for each indicator c. Consider visualizing the average per stakeholder group or per lifecycle stage if performing a comparison or enhancement type of study (Make sure this aligns with the goal and scope of the analysis) B. For low-detail analysis whose results will be used in a more detailed study a. Highlight the higher impact areas of the study • Stakeholder groups • Lifecycle processes C. Explain any limitations in the study a. Limitations due to data availability b. Limitations due to financial or time resources c. Limitations in access to stakeholders or experts D. Make recommendations about: a. Most significant contributors to positive and negative impacts b. How to reduce negative impacts or increase positive impacts E. Re-assess results and determine if analysis should be performed again a. Depends on goal and scope of the study • Some studies perform a screening study to determine the areas of interest for a subsequent, more detailed analysis b. Use the results to determine areas where the analysis could have been done differently F. Provide recommendations based on the results a. Recommendations should align with the goal and scope, selected lifecycle stages and stakeholder groups b. Recommendations should assess highest social impact results

The framework is divided in four assessment stages that are compatible with ISO 14040, the standard that provides the guidelines to perform environmental lifecycle assessments [3]: *goal and scope, inventory analysis, impact assessment and interpretation of results*. At each assessment stage, a set of guiding questions or statements aim to aid the user at each step of the process.

5.2.2 How is the framework implemented?

5.2.2.1 Goal and scope stage

This first step of the framework aims to describe the study being performed be describing why the study is being perform and what is included in the analysis. The decisions made at this stage of the analysis are important because they have a profound effect on the rest of the analysis. Table 17 shows a template to summarize the information for the goal and scope stage of the analysis. The summary should define the reason for performing the study and a definition of the system boundaries. Also, the type of analysis being performed is defined (informative, comparative or enhancement) as this has major implications on the steps to follow for subsequent stages of the analysis.

Table 17: Goal and scope information for rooftop solar panel case study

Define the goal/objective of the study	
What is the study objective?	
Are processes considered?	
Evaluation of company conduct	
Level of Detail	
Study timing	
Reason for study	
Single or multiple products?	
Define the product functionality	
Define the scope of the study	
Spatial scale of analysis	

Analysis type	
Initial system boundaries	
Lifecycle stages considered	
Associated activities	
Stakeholder groups considered	
Functional unit	

5.2.2.2 Inventory Analysis

The objective of the inventory analysis is to define the data that is used to perform the social impact assessment by means of the selection of the indicators used in the analysis. The selection of indicators in an SIA is seen as a major source of uncertainty by experts. Even though there are many qualitative and semi-quantitative methodologies to establish agreement among the selection of the indicators used in the analysis, there are many factors that affect the final list of indicators. First, the selection of relevant indicators must match the goal and scope of the analysis. Second, there isn't a universal list of indicators to choose from when performing an SIA. Although the lack of a universal set of indicators is also criticized, the breadth of applications of SIA makes it difficult to have a single set of indicators that would cover any situation. As part of the systematic mapping procedure, a database of indicators was created and organized. This indicator set is used as the starting point of the inventory analysis. The steps described below are followed to select the list of indicators for this analysis:

1. Refer to the indicator database shown in Appendix E
2. Select relevant indicators based on the goal and scope of the case study
    a. For each indicator, identify the following:
        - Indicator name

- Indicator type: quantitative, semi-quantitative or qualitative
- Desired direction or direction of positive social impact: positive or negative
- Data collection method for indicator: primary (directly from source) or secondary (from indirect sources)
- Scale of indicator: State, region, industry sector or company
- Social impact category as per the Guidelines of Social Assessment of Products from United Nations Environmental Program (UNEP) [10]
    - If a new social impact category is desired, provide enough detail for the reader to understand why it is necessary
- Stakeholder group(s) as per the Guidelines of Social Assessment of Products from United Nations Environmental Program (UNEP) [10]
    - If a new stakeholder group category is desired, please provide enough detail for the reader to understand why it is necessary
- Source of indicator

3. Perform indicator data quality assessment using the modified matrix method provided in the framework
4. Update list of indicators based on the results of the data quality assessment
5. (Optional) Benchmark list of indicators using stakeholder input
    a. When there is access to the stakeholders and when performing a high-detail analysis, use stakeholder input data to validate the list of indicators used in the analysis
6. Define the performance reference points (PRPs) used for the quantitative indicators

The next step is to perform a data quality assessment of the data collected for each of the indicators. Because this is an informative, low detail type of study, all of the data will be collected from secondary sources.

Table 18 shows the data quality matrix assessment method recommended in this framework. The method is based on the data quality assessment presented in the 2018 Handbook for the Social Impact Assessment of Products [138] and the Pedigree matrix of Weidema et al. [170]. Each column represents the criteria used in the assessment. Each row provides the criteria needed to assign the data quality score. The scores range from 1 (best) to 5 (worst). The assessment is based on the following four criteria: (1) *accuracy, integrity and validity, (2) timeliness or temporal correlation, (3) geographical correlation, and (4) technological correlation.* Accuracy, integrity and validity relates to the sources of the data, the acquisition methods used to gather the data, and the verification procedures used to collect the data [138,170]. Timeliness or temporal correlation refers to the time correlation between the time of the study and the time of collection of the data [170]. Geographical correlation refers to the correlation between the area under study and the area of the collected data [138,170]. Technological correlation refers to aspects of the enterprises, industries, and/or characteristics between the technology or product under study and the collected data [138,170]. As stated by Weidema et. al [170], it is important to see how each of the data quality indicators is assessing an independent aspect of data quality. In addition to assessing the data quality of the collected data, the results of the data quality matrix method should highlight the possibilities of improving the quality of the data being collected by evaluating the results for each of the data quality indicators. The resulting average score value must be less than 3 in order to pass the quality assessment test.

Table 18: Data quality assessment criteria.

Criteria		Accuracy, integrity and validity		Timeliness	Geographical correlation (non-company)	Geographical correlation (company)	Technological correlation
Score		Primary data	Secondary data				
1	Data used for screening analysis should be >= 3	Verified data based on measurements	Reports from more than one well-established independent organization	Data from current reporting period (or <1 year old)	Data from area under study	Data from specific site under study	Data from enterprises and processes under study
2		Non-verified data with documentation or verified data partially based in assumptions	Report from a well-established report organization	Data from previous reporting period (between 1 and < 2 years old)	Average data from larger area where area under study is included	Data from other sites of the company in the same region	Data from processes under study but from different enterprises
3		Non-verified data based on assumptions or grey data	Independent but similar claims made by various sources	Data is 2 years old	Data from area with similar production conditions	Data from relevant sites of the company in other regions	Data from processes under study but from different technology
4	Acceptable for internal use only	Qualified estimate (i.e. by expert) or non-scientific report	Unverifiable claims found on internet and social media	Data is 3 years old	Data from area with slightly similar production conditions	Data from other companies in the same region with similar production conditions	Data on related processes but from same technology
5		Non-qualified estimate or unknown source	Non-qualified estimate or unknown source	Data is more than 3 years old	Data from unknown area or area with very different production conditions	Average sector or country data from public or third-party database provider	Data on related processes but from different technology

5.2.2.3 Impact Assessment

The objective of the impact assessment stage is to provide a meaning to the list of indicators created in the inventory analysis section. The first step in the impact assessment stage is to define performance reference points (PRP) for the quantitative indicators. PRPs are threshold values used to provide meaning to the quantitative data. They provide a reference from which to quantify the impact of the quantitative indicators. The reader should refer to Table 23 for a definition of the different PRP scales and how each of these may affect the analysis.

The impact assessment consists of qualitative, semi-quantitative and quantitative indicators. All values are normalized to a scale between 0-1, where 0 represents the lowest social performance and 1 represents the best social performance. Because the final indicator values are assumed to represent positive social performance, the normalization procedure for indicators with different directions of improvement are different. For quantitative indicators, the range between the minimum and maximum reference values are used to normalize the quantitative indicator:

$$Indicator_{norm} = \frac{Indicator}{(PRP\_\max - PRP\_\min)} \tag{1}$$

There are two types of semi-quantitative indicators used in the framework, yes or no questions and a Likert scale with values between 1 and 5. To quantify yes and no questions, a yes is equal to a value of 1, and a no is equal to a value of 0. For Likert type questions, the normalization depends on the direction of improvement of an indicator. For an indicator where the desired direction of improvement is positive (5 represents the best social performance and 1 represents the worst social performance), the normalization procedure is the following:

$$Indicator_{norm} = \frac{(Indicator - 1)}{4} \tag{2}$$

For an indicator where the desired direction of improvement is negative (1 represents the best social performance and 5 represents the worst social performance), the normalization procedure is the following:

$$Indicator_{norm} = \frac{(5 - Indicator)}{4} \tag{3}$$

As with semi-quantitative and quantitative indicators, the final results are normalized between 0 (worst social performance) and 1 (best social performance). Table 19 shows the recommended quantification adopted from the Product Social Impact Assessment (PSIA) framework [171]. The quantification is based on the performance of the qualitative indicator relative to the PRP.

Table 19: Quantification of qualitative indicators.

Value	Level of Compliance
1	Ideal Performance
0.75	Progress beyond compliance
0.5	Compliance with PRP
0.25	Non-compliant to PRP but improving

0	Non-compliant and no signs of improving

5.2.2.4 Interpretation of Results

The objective of the interpretation of results stage is to identify the greatest contributors to social impacts and to propose changes to improve such impacts based on the results from the impact assessment stage. This stage consists of summarizing the main learnings from the analysis. The strategy used in summarizing and communicating the results should align with the desired question to be answered by performing the study. In other words, the interpretation of results should align with the goal and scope definition of the analysis. The use of aggregation is not recommended to establish conclusions about the potential social impacts of the analysis, but rather as a strategy to facilitate comparison. The recommended strategy is to interpret each indicator individually; in addition to providing a numerical result, a narrative of the results obtained in the analysis should be provided. The aim of recommending a narrative is to provide a complete interpretation of the results to the reader, an interpretation that may not be clear from a single number.

The use of aggregation should also follow the type of analysis being performed. When performing an informative study, no aggregation is recommended as the goal of the analysis is to understand the potential impacts of a single product system. When performing a comparative or enhancement type of study, the goal is to compare the social impacts among different alternatives. In this type of study, aggregation is only recommended to facilitate the comparison among different alternatives rather than to draw conclusions about social impacts. Aggregation may also facilitate comparison among different stakeholder groups or among different product lifecycle stages, which again is only recommended to facilitate comparisons. Regardless of the aggregation strategy implemented, the aim is to select a strategy that aligns with the goal and scope of the analysis.

5.2.2.5 What makes the framework novel?

There are two aspects that make the SIA framework presented in this thesis novel. The first aspect is that it is the first framework that uses a set of identified SIA challenges as its starting point. The SIA framework maps the individual challenges to each of the SIA assessment stages (goal and scope, inventory analysis, impact assessment and interpretation of results) and then maps each of these challenges to methods for how to overcome them. Table 20 shows how each of the identified challenges maps to each assessment stage. This mapping from assessment stage to method is expected to provide a more holistic approach to addressing SIA challenges, rather than the status quo approach of current studies, in which a solution method is presented for individual or a smaller subset of the challenges. By adopting this approach, the aim is to contribute to the development of a standard framework that is applicable to most problems, rather than providing a solution to a single challenge. For each of the challenges, the user is presented with a database of methods to overcome it, and with a database of previous SIA studies that are applicable to different assessment scenarios, obtained from the systematic mapping procedure. General recommendations, advantages and disadvantages of the different methods are provided to the user to help them make an educated decision about which method to use and why. By combining the identified challenges, how they relate to each SIA assessment stage, the methods and databases, the framework attempts to serve as a central source of information; time and effort will be saved for the user as all of the needed information is found on a single document. Still, it is advised that the challenges, methods and databases provided are limited to the findings of the systematic mapping procedure, and that there potential exists additional valuable information outside of the scope of the completed literature review.

The second aspect that makes the framework novel has to do with the goal and scope assessment stage of the analysis. An analysis classification scheme adapted from the work of Kjaer et al. [172] on product service systems, classifies the analysis into one of the following three types: *informative, comparative* or *enhancement.* Current S-LCA studies don't explicitly make such a distinction, and it is recommended because the type of analysis being performed is linked to recommendations for the remaining SIA assessment stages. For an informative type of study, the impact assessment results for quantitative indicators should be presented individually without any averaging. For comparative or enhancement studies, it is recommended to use a common indicator database for all products being analyzed. It is only for the comparative or enhancement types of analysis that aggregation is recommended, and it should only be used to compare the SIA results of the different products or concepts being examined.

Table 20: Mapping of challenges to SIA stages

Assessment Stage	Related Challenge
Goal and Scope	• Challenge #3: Use of a functional unit • Challenge #9: Definition of system boundaries • Challenge #12: Selection of stakeholders • Challenge #10: Selection of global or location specific data
Inventory Analysis	• Challenge #6: Connection of social impacts with products • Challenge #7: Definition of social well-being • Challenge #1: Selection of social impacts • Challenge #4: Quality criteria for collected data
Impact Assessment	• Challenge #2: Sources of uncertainty • Challenge #8: Selection of impact assessment method
Interpretation of Results	• Challenge #5: Allocation of social impacts • Challenge #11: Methodology to report final results

5.2.2.6 How are the challenges being addressed in the framework?

Based on the systematic mapping, a database of methods for each of the challenges have been created. The goal of this database is to provide users with a comprehensive list of methods in a single location rather than having the user search in the literature for these methods. In addition, the document provides general recommendations on when to use the provided methods. The methods are organized based on each of the identified challenges.

Challenge #1: Selection of social impacts

The novel SIA framework presented in this thesis is what is known as a type I impact assessment framework. A type I method performs an SIA based on the value of indicators relative to performance reference points (PRP) [2]. This is different from a type II method, in which the impact assessment is based on establishing causal links between inputs and their resulting social impacts, also known as impact pathways [2]. For a type I framework, the selection of the relevant social impacts comes down to the selection of relevant indicators to perform the analysis. Before reviewing the methods available to select among the indicators, it is recommended that the user define the approach of the analysis as one of the following:

1. Process approach: the study will select indicators according to the processes performed at each of the lifecycle stages of interest
2. Company approach: the study will select indicators to evaluate company conduct
3. Process and company approach: both, processes and company conduct are considered during the selection of the indicators

The method used for the selection of indicators depends on numerous factors that are related to the goal and scope of the analysis, data availability, financial and temporal resources, and access to experts and stakeholders. Table 21 shows a summary of methods to select relevant indicators based on the resources available to the user. The reader is advised that although the list is very informative, it is not a complete list of all indicator selection methods available. The user is advised to select the relevant methods based on the available resources.

Table 21: Summary of methods for indicator selection

Method	Explanation	Is access to experts or stakeholders required?	Primary or secondary data	Source
Participatory Approach	Gathers stakeholder or expert feedback to determine relevant indicators	Yes	Primary	[137]
Screening study results	Use results from screening or low-detail SIA that highlights areas of concern	Yes/No	Primary or Secondary	[2]
Materiality assessment results	Use results from materiality assessment to determine relevant topics	Yes/No	Primary or Secondary	[138]
Delphi Method	Requires consensus among experts	Yes	Primary	[47]
Social hotspot database	Use social hotspot database indicators to determine areas of interest in analysis	No	Secondary	[8]
Social hotspot analysis	Use stakeholder and/or expert input or secondary data to determine relevant indicators.	Yes/No	Primary or Secondary	[1]
Activity variables	Provides relative importance of process based on a quantitative measure. Examples include number of worker hours in process or	Yes/No	Primary or Secondary	[1]

	relative value added by process.			

Challenge #2: Sources of uncertainty

Although there are many sources of uncertainty in the activities of an SIA, the following four are considered as the most significant ones: indicator selection, aggregation procedures, the selection of performance reference points (PRP), and weighting methods. A brief definition of each uncertainty source is provided, along with recommendations and methods for how to perform such steps.

Indicator Selection

As mentioned in numerous occasions in this thesis, the selection of indicators is a major source of uncertainty due to the subjectivity involved in the process. Methods for selecting indicators are already shown in Table 21. The recommendation is to start with a low-detail or screening study that attempts to cast a wide net. The results from such a study are then used to justify the relevance of the selected indicators. It is then recommended to verify such a list using either stakeholder input or expert input. The use of external input is even more recommended in studies where there are no existing indicators and the user has to develop a new set of indicators to complete the analysis.

Aggregation and weighting procedure

Aggregation refers to the numerical grouping of indicators at different levels of the analysis. Aggregation can be done at the social impact category, product lifecycle stage or stakeholder group level. The level of aggregation is determined by the goal and scope of the analysis. In other words, it depends on the desired learning from the assessment. The aggregation methods are similar to weighting methods because aggregation is indeed a weighting procedure that aims to condense a group of metrics to a single grouping. This is why the aggregation and weighting procedures are shown in the same chart. Table 22 provides a summary of aggregation and weighting methods. Some of the methods are similar to the ones shown for indicator selection. This similarity results from the fact that indicator selection may involve weighting and/or ranking procedures. The reader is directed to the work of Sierra et. al [47] for a more extensive recollection of weighting methods used in sustainability applications.

In this framework, aggregation is only recommended under certain conditions. When performing an informative type of analysis, meaning that a single product is being studied, no aggregation is recommended among the indicator results. Aggregation is only considered in comparison or enhancement assessments. The reason for the aggregation is to be able to perform a comparison between the product alternatives. The level of aggregation should be performed at a level that matches with the goal and scope. For example, if the user aims to understand which of the products has a higher impact on the workers stakeholder group, then aggregation should be done at the stakeholder group level. This aggregation level will allow for the comparison of the different product alternatives with regard to the social impact on the workers stakeholder group. Regarding weighting, this framework only recommends weighting if there is access to expert or stakeholder data that justifies the weighting values. The user is thus recommended to select aggregation and weighting methods that align with the goal and scope of the analysis and also with the available data, time and financial resources.

Table 22: Aggregation and weighting methods.

Method	Explanation	Is access to experts or stakeholders required?	Primary or secondary data	Source
Participatory Approach	Gathers stakeholder or expert feedback to determine relevant indicators	Yes	Primary	[137]
Screening study results	Use results from screening or low-detail SIA that highlights areas of concern	Yes/No	Primary or Secondary	[2]
Materiality assessment results	Use results from materiality assessment to determine relevant topics	Yes/No	Primary or Secondary	[138]
Delphi Method	Requires consensus among experts	Yes	Primary	[47]
Social hotspot database	Use social hotspot database indicators to determine areas of interest in analysis	No	Secondary	[8]
Social hotspot analysis	Use stakeholder and/or expert input or secondary data to determine relevant indicators.	Yes/No	Primary or Secondary	[1]
Activity variables	Provides relative importance of process based on a quantitative measure. Examples include number of worker hours in process or relative value added by process.	Yes/No	Primary or Secondary	[1]
Rank Order Weight Distribution (ROD)	The method starts by performing a ranking procedure between 2-10 criteria and then provides weighting values for each of the criteria	Yes	Primary	
Analytic Hierarchy Process (AHP)	Structured technique for multi-criteria decision making based on a pairwise comparison scale	Yes	Primary	[47]

Simple Additive Weighting (SAW)	Technique that determines an average weighting for each alternative through the addition of the contribution of each attribute multiplied by its weights	Yes/No	Primary or Secondary	[47]

Selection or development of PRPs

The selection of PRPs to be used in the analysis is another source of uncertainty because of the subjectivity that may be involved in its selection. Whenever possible, this framework recommends agreement among different researchers regarding the list of PRPs. PRPs should be selected based on geographical and technological agreement with the indicators being used in the analysis.

Table 23: Advantages and disadvantages of PRP scale levels.

PRP Scale Level	Advantages	Disadvantages
International [173]	Useful to evaluate global value chains	Represents only minimal standards due to their global applicability; too general for regional analysis
National [174,175]	Useful to understand the value of an indicator with respect to the country's average performance	Not useful to evaluate global or national product chains
Sector [176]	Useful to understand sectoral performance and to compare companies in the same sector, to understand social differences among industry sectors, which is very important when evaluating working conditions	Not useful to evaluate global or national product chains

Regional [123]	Provides insight regarding the social conditions in the region, which is essential in countries where there are significant social variations among different regions	Limited applicability to international scale and requires a significant amount of time and financial resources to gather the data; not necessary for small countries where there is little to no variation among the social conditions
Product or technology	Provides the information based on the product or technology itself, rather than its location; useful for decision-making among different technologies	Not useful when the scope of the analysis is not the product or technology itself

Table 23 summarizes the advantages and disadvantages of the different geographic scales for the PRPs [123]. The scale of the PRP should reflect the scope of the analysis and the questions to be answered. There are situations in which the user is forced to select a different scale than desired due to data quality or availability limitations, but this should be disclosed as such in the limitations of the analysis. There are situations in which the user does not find any relevant PRPs for the analysis. The reader is then referred to the work of Siebert et. al [124], in which a procedure to generate context-specific PRPs is shown.

Challenge #3: Use of a functional unit

The use of a functional unit is a point of debate in the SIA community, as it is found to be a methodological challenge to link social effects to functional units [48]. A review by Petti et al. [24] showed that out of thirty-five S-LCA studies, twelve considered a numerical functional unit, eighteen applied a non-numerical functional unit and five didn't cite any functional unit at all. In this framework, the use of a numerical functional unit definition is encouraged when possible, but it is also recognized that there might be limits to the ability to link qualitative criteria to a functional unit. If a non-numerical functional is used, it is recommended that the user provides enough justification for the reader to understand the decision. In addition, this framework does recommend the use of a functional unit when performing comparative studies. In a comparative study, it is important to have a unit of reference for the social impacts being compared, otherwise the risk of misinterpretation is very high [48]. In addition, this framework encourages the use of a functional unit if the results of the SIA will be combined with an Environmental LCA. Table 24 shows three different methods to link qualitative indicators to functional units. The working time and import fraction concepts are known as activity variables. Activity variables are expected to "reflect the share of a given activity associated with each unit process"[2,165].

Table 24: Summary of methods to link data to functional unit.

Method Name	Definition
Scoring approach [125]	Qualitative indicator values are converted to a Likert scale and then linked to the functional unit
Working time approach [165]	Link process to functional unit based on time spent at that process relative to the rest of the lifecycle processes
Import fraction [177]	When dealing with imported resources, use the relative import fraction to link processes to the functional unit

Challenge #4: Quality criteria for collected data

Data collection is accepted by numerous authors as a significant barrier to scientific accuracy in SIA [150,164,171]. This framework provides a pedigree-matrix based qualitative method to assess the quality of the data being collected based the following four criteria: (1) *accuracy, integrity and validity, (2) timeliness or temporal correlation, (3) geographical correlation, and (4) technological correlation.* The methodology is explained in more detail in the rooftop solar panel case study. Such a strategy for primary and secondary data collection is recommended for screening studies. For high detail studies where primary data is being collected, the user is encouraged to use one of the data validation techniques shown in Table 25 in addition to the matrix assessment type provided in this framework.

Table 25: Primary and secondary data validation methods.

Method Name	Definition	Primary or Secondary data
Data validation [144]	Data validation based on onsite visits. Use this method when the primary data being used is not collected by the authors performing the study	Primary
Triangulation Technique [178]	Collect data from different sources to identify any bias in the data. Use this method when collecting data from individuals that may be forced or may benefit from biased data	Primary or Secondary
Data cross-check [6]	Compare primary collected data with secondary sources. This method only works if there is secondary data available for the primary data being collected.	Primary

Challenge #5: Allocation of social impacts

Allocation refers to the numerical grouping of social impacts (indicator values). In the novel framework, the use of allocation procedures depends on the type of analysis being performed. For an informative type of analysis where only a single product or technology is being assessed, the use of allocation is discouraged. It is therefore recommended the user to interpret each indicator value individually, as the goal of the assessment is to understand the potential social impacts of the system. Allocation is only recommended when performing comparative or enhancement type studies. In a comparison type, the allocated result should ease the comparison of different products, technologies or different concepts of the same product. In an enhancement type of study, allocation allows for the comparison of "optimized" models of a product relative to previous or unoptimized versions. The level of allocation should occur at a level that matches with the goal and scope of the analysis, which is why it is so important for the user to determine this during the goal and scope assessment stage. This is necessary so that the expression of the indicators allows for the desired allocation procedure. For example, if a user aims to compare the results from different stakeholder groups, the indicators should be expressed for each stakeholder group rather than using the same indicator for multiple stakeholder groups.

The reader must be warned that the term allocation may refer in some articles to the distribution of the final impacts to different processes of the product lifecycle. In that regard, the reader is directed to the work of Grubert [164], where she provides an excellent explanation of the issues with allocation in LCA and recommends an allocation approach.

Challenge #6: Connection of social impacts with products

The connection of social impacts with products rather than with the conduct of companies is always a challenge [123]. Consider the comparison of the same product with two different supply chains. Even though it is the same product, the results from the SIA will differ, due to the different conduct of the companies and the stakeholders considered in the analysis. Although such an event is common, it is recognized that the goal of a SIA is not to connect social impacts with products, but rather to inform about their potential social impacts. Under that logic, this challenge mainly depends on the goal and scope of the analysis. It is thus recommended to explicitly state if products are being assessed, if company conduct is being assessed or if both aspects are being studied. The analysis for the product and the company should be conducted separately, even if in the interpretation phase of the results, aggregation is performed for ease of comparison.

Challenge #7: Definition of "social well-being"

The definition of social well-being is an important concept in SIA because its aim is to improve the human condition. The concept of human well-being provided implicitly in the novel SIA framework presented in this thesis is adopted from the 2009 UNEP Guidelines and its expression through stakeholder theory [2]. Instead of directing the reader to a certain definition of social well-being, the reader is referred to Table 26 for a list of articles that provide different definitions of social well-being that could be used as a reference. Because it is recognized that SIAs are used in a variety of applications, there may be situations where it would be more appropriate for users to develop their own method based one definition of well-being that aligns better with the goal and scope of the study.

Table 26: Social well-being definitions.

Method Name	Definition of social well-being
2009 UNEP/SETAC Guidelines [2]	Well-being is defined as the state of an individual's life situation and is linked to the five stakeholder groups used for the analysis.
PROSUITE [107]	Well-being consists of the following four areas of concern: autonomy; safety, security and tranquility; equality; participation and influence.
PSIA [6]	5 capital approach to well-being: human capital, social capital, physical capital, economic capital and natural capital.
Rainock et. al [19]	Social capital, health and fertility and mental health.
Hicks et. al [179]	Human well-being is defined as "a state of being with others, where human needs are met, when individuals can act meaningfully to pursue self-defined goals, and when they can enjoy a satisfactory quality of life."
Keyes [180]	Well-being is defined "as the appraisal of one's circumstance and functioning in society."
United States Institute of Peace (USIP) [181]	Defined as "an end state in which basic human needs are met and people are able to coexist peacefully in communities with opportunities for advancement."

Challenge #8: Selection of impact assessment method

Because there is no single, standardized methodology to perform the impact assessment stage of the SIA, there is a significant number of methodologies found in the literature. The methodology presented in this framework is based on PRP, and it provides normalized values between 0 (worst social performance) and 1 (best social performance. The impact is based on stakeholder-theory, and it handles qualitative, semi-quantitative, and quantitative indicators. The normalization procedure depends on the type of indicator and takes into account the desired direction of improvement for each of the indicators when performing the normalization. The impact methodology for this framework is illustrated in detail in the case study explanation in this same chapter.

Recognizing that there is no single standard for impact assessment, the reader is provided in Appendix D with a database of impact assessment methods. Each method is classified based on the following variables: use of stakeholder theory, functional unit, primary or secondary data, expert or stakeholder consultation, quantitative or qualitative indicators, and procedure to perform the impact assessment.

Challenge #9: Definition of system boundaries

The definition of the system boundaries is crucial, as it determines what processes and ultimately what stakeholder groups are included in the SIA. This novel SIA framework recommends setting system boundaries based on the goal and scope of the study. The recommended strategy is to perform a two-phase analysis, where an initial, lower detail study is performed first and includes all product lifecycle and stakeholders of interest in the analysis. In addition, the user should consider if the results of the SIA will be coupled with other LCA analyses and understand how the definition of the system boundaries will affect the coupling of the results. The results from this analysis are then used to refine the system boundaries for a more detailed analysis. Table 27 shows a summary of different methods to define the system boundaries.

Table 27: System boundary definition methods.

Article name	Method	Comment
Development of social sustainability assessment method and a comparative case study on assessing recycled construction materials [125]	All stakeholders must be included	Recommended for low-detail or screening studies
Development of a methodological framework for social life-cycle assessment of novel technologies [142]	Use same boundaries as in E-LCA	Not recommended for detailed SIA because having fixed boundaries may disregard important social hotspot not affected by the E-LCA. Use with caution.
GreenZee Model [145]	System boundaries are determined by the product lifecycle stages	Not useful if only one lifecycle stage is being analyzed
Social life cycle assessment for material selection: a case study of building materials [1]	Only include processes that are affected by the company management decisions	Recommended when evaluating company conduct
A survey of unresolved problems in life cycle assessment [116]	Setup initial conservative system boundary and keep adding processes that show significant impact on the results	Very time and data intensive; only recommended for purely quantitative analysis that allow partial addition of processes

Challenge #10: Selection of global or location specific data

The results from the expert feedback activity presented in Chapter 6 resulted in the elimination of this as a challenge. This is seen more as an issue with the design of the SIA rather than a challenge to performing an SIA. Still, it is understood that this might present difficulties to some users, which is why recommendations are still provided. The use of global or location specific data should be guided by the goal and scope of the analysis and by the system being analyzed. Global data is recommended for screening studies, where the results of the system being analyzed are interpreted with respect to international or global standards or agreements. If the intent of the analysis is to understand impacts that are regional, or the user wants to understand how the system being analyzed compares with similar systems in the same country or economic sector but in a different region, then location specific data is necessary. Again, the use of local specific data is limited by its availability and by the resources available to gather such data if desired.

Challenge #11: Methodology to report final results

Based on the expert feedback exercise in Chapter 6, this is not considered a challenge to SIA but rather more an issue of how to report and communicate the findings of the study. There are a handful of methodologies found in the literature to present the final results of the SIA. It is recommended that regardless of the method being used, the user must be transparent on how those results are obtained, especially if there is any aggregation performed. Table 28 provides a summary of different methods to report the results of the SIA.

Table 28: Methodologies to report final results of SIA.

Article name	Methodology	Numbers or Color scale	Comments
The social footprint of hydrogen production - A Social Life Cycle Assessment (S-LCA) of alkaline water electrolysis [160]	The results are expressed using Social Risk Points (SRPs), which are the units of the Social Hotspot Database	Number	Only useful if using the Social Hotspot Database in the analysis or if there is a definition of risk involved
Introduction to evaluating energy justice across the life cycle: A social life cycle assessment approach [128]	Give score of + for positive impacts, - for negative impacts and * for neutral for each of the lifecycle stages	Color scale	Useful for low-detail studies evaluating the impacts at the lifecycle stages
The Sustainable Child Development Index (SCDI) for Countries [182]	Final results are expressed in an	Numbers	Too simplistic for detailed analysis but the results are still

	integer scale between 1 and 4		quantitative, which might of interest for some users
Social life cycle assessment in Indian steel sector: a case study[150]	Results are reported for each lifecycle stage with a value between 0 and 1	Numbers	The use of decimal values allows for comparisons of more detailed studies.
Social Sustainability Assessment of Canadian Egg Production Facilities: Methods, Analysis, and Recommendations [154]	Results are color coded based on one of the following assessment results: not assessed (black), risky (red), compliant (white), proactive (dark green) and committed (green)	Color scale	The method is recommended when evaluating company conduct or company practices; the goal here is to interpret the risk in the company behavior
Product Social Impact Assessment (PSIA) [6]	Results are reported with one of the following five integers: -2 (ideal performance), -1 (progress beyond compliance), 0 (compliance with local laws), +1 (non-compliant situation but improving) and +2 (no-data or non-compliant situation)	Number and color scale	This method is recommended if the user has interpretations of the indicators results based on the reference values, otherwise it is hard to establish what each of the integer values mean. The user should be careful to not interpret differences in a values as actual numerical representations of a situation being better or worse, meaning that +2 is not twice as good as +1

Challenge #12: Selection of stakeholders

The framework presented in this dissertation is based on stakeholder-theory, and it uses the same groups as the 2009 UNEP/SETAC Guidelines [2]. The framework recommends selecting stakeholders based on the goal and scope. As with the definition of the system boundaries, it is recommended to perform a two-step approach, where the results from a low-detail, screening study are used to refine the selection of the stakeholder groups that are most at risk for social impacts. Again, for an informative study, it is recommended to include all stakeholder groups in the analysis. For detailed analysis, it is also recommended to use expert or stakeholder input to further define the relevant stakeholders in the analysis. The use of secondary data to determine the relevant stakeholder groups should only be done in low-detail studies.

5.3 Limitations of SIA framework

As with any metric based framework, the main limitation of this framework is the risk of misinterpreting the social impacts for each of the stakeholders considered in the analysis. The goal of this framework is to support decision-making for experts, experts that are evaluating the social impacts of the system being analyzed, based on their own interpretation. In SIA, local context becomes extremely important, meaning that a set of identified social impacts in a region or a group of individuals may be seen in a totally different manner by a different group of individuals. When performing the analysis, one has to respect the opinions and input from the stakeholders, as they are the ones being affected by the system being studied. As an expert, one has to redefine the term expert, in the sense that the stakeholders are the experts themselves, with regard to what affects them and how. This is why it is recommended that the list of indicators is verified by using stakeholder input. There are some instances in which such an exercise may not be possible, either because of a lack of resources or because there is no way to reach the stakeholders and ask for their input. As with any stakeholder analysis, the individual or group of individuals performing the analysis must respect the stakeholder opinion and must avoid at all costs defining what is best for the stakeholder based only on a technical expertise.

5.4 Conclusions

A novel SIA framework is presented. This is the first framework that is developed from a recurring set of challenges identified through a systematic mapping of the SIA field. The goal of the framework is to provide novice and expert user guidance on how to perform an SIA of a product system. The framework adheres to the LCA structure with the intention of advancing the field towards the development of a standard methodology to perform SIA.

From a conceptual standpoint, the quantitative evaluation of social impact metrics has to be done carefully. Quantitative results are beneficial for comparison among different products, technologies or concepts, and they are beneficial for communicating the overall results of an analysis. Aside from their known benefits, quantitative results in SIA must be interpreted with caution. Although it might be tempting to only interpret the numerical results of the analysis, it is recommended to understand the results of the indicators individually. Certain social impacts are more difficult to quantify than others, and users must put forth as much effort as is needed to avoid interpreting social issues as numbers. The overall consensus in this document is that quantitative analysis of social impacts has many benefits, but their interpretation requires increased effort; for example, a value of 2 versus a value of 1 does not mean that the social aspect being evaluated is twice as good.

CHAPTER 6 NOVEL SIA FRAMEWORK DEVELOPMENT: EXPERT FEEDBACK

6.1 Introduction

The development process of a design support tool has many parallels with the development process of a tangible product. The creation of a design support tool aims at providing the user with the means to address a particular need in the design process. For the SIA framework, the user needs are the challenges identified in the systematic mapping process, described in Chapter 4. Recognizing the importance of feedback in the development of the novel SIA framework, this chapter presents the methodology used to gather and analyze expert feedback with regards to the findings of the systematic mapping process, and a summary of the feedback provided. The feedback is used to evaluate the validity and relevance of the identified challenges. By having a set of identified challenges, the novel SIA framework can then focus on helping the user overcome such challenges.

6.2 Methodology

38 experts were contacted online to gather their feedback using the electronic survey package Qualtrics© [183]. Only 6 of the experts completed the survey, resulting in a 16% completion rate. The experts consisted of academic and industry experts performing research on the topics of social impact assessments and/or environmental LCA. The experts that were contacted to complete the survey were located on all continents, but the ones that completed the surveys were located either in the United States or Europe. The list of experts was populated from individuals that authored the sources gathered in the systematic

mapping procedure. The survey started by collecting demographic data from the experts and then went into collecting feedback for each of the challenges. A brief explanation was provided for each of the challenges to reduce any misinterpretation, followed by a set of questions. The set of questions was similar for all challenges, as follows:

- Do you think that the articulated challenge to performing social impact assessments exist?
- How frequently have you encountered this challenge when performing social impact assessments?
- How important is addressing this challenge to the success of performing a social impact assessment?
- Please provide any comments, additions or feedback you have related to this challenge

The data collection was performed electronically using the survey shown in Appendix B. Because some of the users were located in the European Union (EU), the survey complied with the latest EU data protection protocols. The results of the Likert type questions and the open-ended questions are summarized for each of the challenges.

6.3 Analysis of results

The results from the Likert type questions and the open-ended questions are combined to assess the validity of the challenges based on the expert feedback. Table 29 shows the classification of each challenge into one of three categories: *Support, mixed support or no support.*

Table 29: Challenge classification based on expert feedback.

#	Challenge	Support	Mixed Support	No Support
1	Selection of social impacts	✓		
2	Sources of uncertainty	✓		
3	Use of a functional unit		✓	
4	Quality criteria for collected data	✓		
5	Allocation of social impacts		✓	
6	Connection of social impacts with products		✓	
7	Definition of "social well-being"	✓		
8	Selection of impact assessment method	✓		
9	Definition of the system boundaries	✓		
10	Selection of global or location specific data			✓
11	Methodology to report final results	✓		
12	Selection of stakeholders		✓	

“Do you think that the articulated challenge to perform social impact assessments exists?”

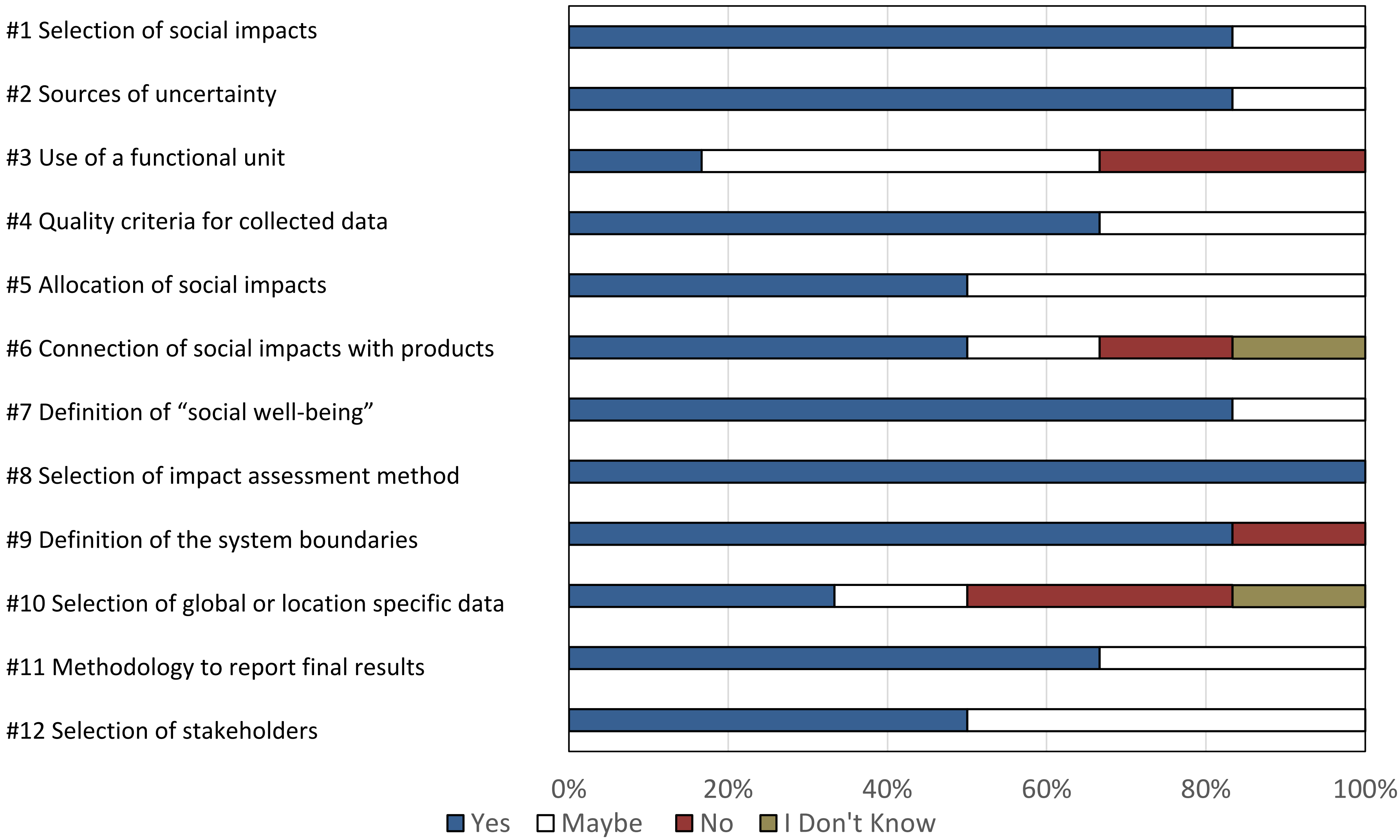


Figure 12: Expert feedback results for question #1 of the survey:
“Do you think that the articulated challenge to perform social impact assessment exists?”

“How frequently have you encountered this challenge when performing social impact assessments?”

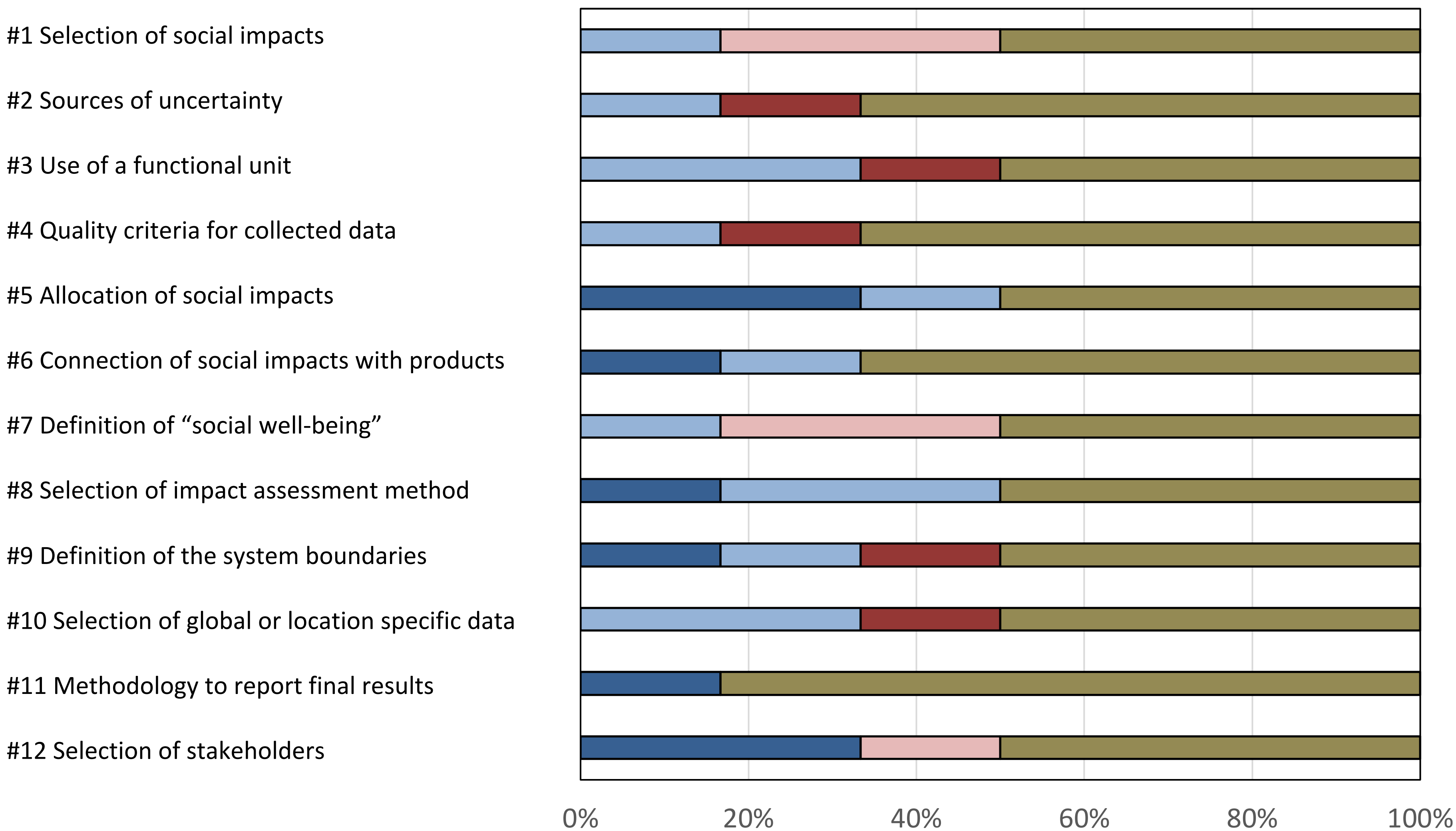


Figure 13: Expert feedback results for question #2 of the survey:
“How frequently have you encountered this challenge when performing social impact assessments?”

“How important is addressing this challenge to the success of performing a social impact assessment?”

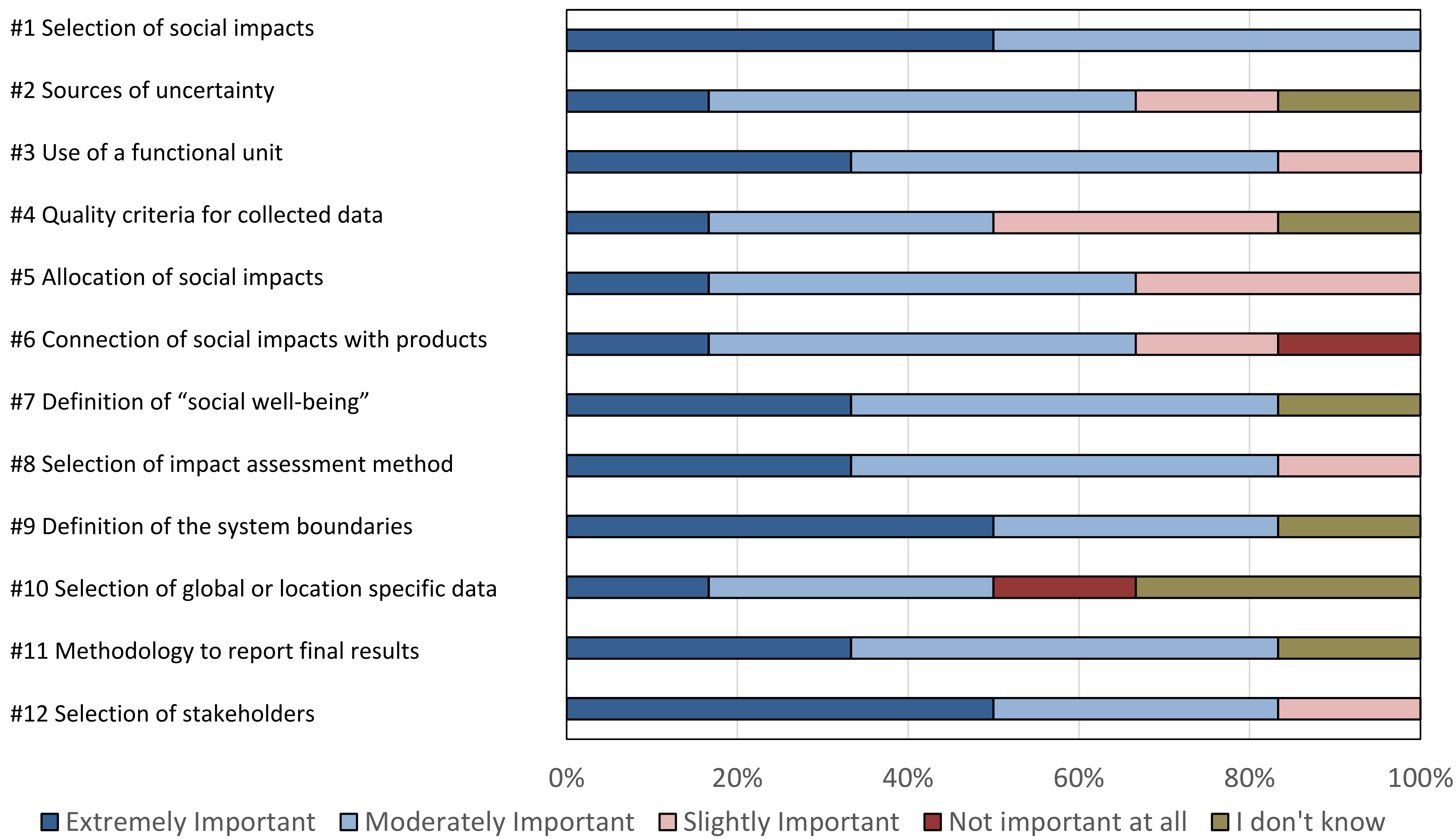


Figure 14: Expert feedback results for question #3 of the survey:
“How important is addressing this challenge to the success of performing a social impact assessment?”

Based on the results provided by the expert feedback data, the following are summaries and synthesis of the findings for each of the challenges:

Challenge #1: Determination of what social impacts to consider and how to quantify them

The definition of a social impact has significant consequences on the ability of communities, for example, to advocate for their best interests. The definition of a social impact should consider whose priorities are reflected when defining what is and what is not considered a social impact. A key aspect of this challenge is the effect of local aspects when defining social impacts, i.e., community A might find social impacts in activities that community B does not see any social impacts. Rather than focusing on how to quantify them, this challenge should only focus on the determination of what social impacts to consider. Those impacts might not be quantifiable, they could rather be assessed qualitatively. This challenge now reads "Determination of what social impacts to consider."

Challenge #2: Uncertainty with indicator selection, normalization, weighting, and aggregation

Some experts believe that having a uniform set of indicators would make the assessment more robust and would ease the ability to compare among the results of different studies. Others believe that having such a uniform set of indicators is not beneficial, as social assessments must incorporate local aspects from the communities being studied, something that wouldn't be possible using a uniform set of indicators. Although comparing across studies is of value, some experts believe that the purpose of an SIA is to capture the impacts to stakeholders, rather than comparing results across geographies and industries. Based on the expert feedback, this challenge is kept unchanged, as all of these aspects are recognized as sources of uncertainty in the analysis.

Challenge #3: Determination of whether a functional unit should be used

Some experts believe that a functional unit is essential to enable comparisons among prospective designs or among different studies, and therefore, to support decision-making. Other experts believe that there are many contexts in which qualitative data without any reference to a functional unit is deemed important. The use of a functional unit should consider the nature of the data being used (qualitative or quantitative) and see how important it is to link it to a functional unit to make it valuable. No changes are made to this challenge based on the expert feedback.

Challenge #4: Determination of minimum criteria to be satisfied during data collection efforts

This challenge is supported by the expert feedback, but some important observations are expressed. First, the degree of minimum criteria to be set during data collection efforts depends on the sensitivity of the data. Second, if data is to be collected from stakeholders, the process of data collection, as well as the information sources, must be evaluated for quality. Overall, the experts agree that this is important, but they don't see how having a universal, minimum set of criteria could be achieved. Instead, the experts recommend strict data quality practices that are tailored to the data characteristics themselves, rather than to define a universal set of criteria to be satisfied. No changes are made to this challenge based on the expert feedback.

Challenge #5: Allocation of social impacts into different categories

To the experts, this challenge seemed more important for analyzing the results rather than performing the SIA. Additionally, some experts mentioned that in certain studies with qualitative data, the categories emerge in the process of data analysis. Based on the expert feedback, this challenge will be kept. In the framework presented in this thesis, the use of allocation is discouraged, and the individual interpretation of indicators is recommended.

Challenge #6: Connection of social impacts with products rather than with the conduct of companies producing the products

One expert expressed that this is one of the main challenges to evaluating the social performance of products. On the other hand, other experts agreed that this is more a problem of how the study is conducted, i.e., the social performance of a product and of a company should be performed separately. This challenge becomes relevant when defining the stakeholders in the analysis. When evaluating the social impact of a product, employees will be affected by both the conduct of the companies and by the design choices, so it depends on the nature and the scope of the analysis. Based on the expert feedback, the consensus is that the challenge still remains; however, in the framework, now there will be a guiding statement that recommends evaluating companies and the product separately. This will allow researchers to clearly distinguish between indicators that are tied to the company and others that are tied to the product itself.

Challenge #7: Definition of “social well-being” used in the analysis

This challenge has major resonance with the discussion of what a "need" is. To determine what constitutes social well-being, will help determine what diverse areas are deserving of social impact assessments. Well-being defined too narrowly means that SIAs can't reach their full potential to influence decisions, design, and policy. Another important observation made by an expert is that impacts don't have to be directly related to social well-being or fit in its definition in order to be significant. For example, the impact of increasing real estate prices will be detrimental to some and beneficial to others, without having to measure social well-being specifically. Based on the expert feedback, this challenge is left unchanged, as it definitely exists and is something hard for practitioners to define.

Challenge #8: Selection of a preferred method to perform the social impact assessments

The experts expressed that the selection of a method to perform the impact assessment is important to be able to compare results of different assessments and ensure consistency of the results, but not necessarily to performing an individual social impact assessment. Having a preferred method for performing an SIA is important when comparing across different studies, but not so much when performing an individual assessment. A benefit of having a preferred method is that it would be universally respected, thus allowing it to be teachable and shareable. Based on the expert feedback, this challenge is left unchanged. Although it is true that having a universal method is not as important to perform an individual assessment, it would be useful for comparing across different studies and to improve communication of results.

Challenge #9: Definition of the system boundaries

The definition of the system boundaries is always challenging because it affects what is considered in the analysis. The selection of the system boundaries always involves a tradeoff between analysis learnings and resources. Having extensive boundaries is beneficial, as they are inclusive of the social impacts considered, but they might make the analysis prohibitive in terms of temporal or financial resources. Having too narrow boundaries results in low financial and temporal requirements, but this might leave out crucial impacts from the analysis. Based on the expert feedback, this challenge remains unchanged.

Challenge #10: Selection of global or location specific data

The experts disagreed that this is a challenge. Instead, the experts see this as part of the design of the SIA. When performing a low-detail, screening analysis, the use of global data is convenient. When performing a highly detailed analysis, it is important to use location specific data. Based on the expert feedback, this statement is not considered a challenge. Although it is still an important aspect of the analysis, it is considered part of the study design itself rather than a challenge, which is why this challenge is removed from the list.

Challenge #11: Selection of scoring scales for reporting the results

Although the experts agree that this is a challenge, the selection of the scoring scales used to report the analysis is more important for reporting the results or for comparing the results across different studies, rather than being a crucial part of performing the SIA. Having an agreed upon scale by which to report the results will benefit communication and transparency, but it seems that what is more important is the procedure followed to obtain those results. Based on the expert feedback, rather than considering this a challenge to perform an SIA, it is considered more as part of the interpretation of the results of the impact assessment, which is why it is removed from the list. Practitioners should select scoring scales that are relevant to the audience to whom they are communicating these. Still, how the impact assessment was performed is most important, which precedes the use of any scoring scales.

Challenge #12: Selection of stakeholders relevant to the study

Experts expressed mixed reviews of this challenge. It is seen more as part of the process of performing the SIA rather than a challenge. The experts agreed that it is essential to include all of the populations affected as stakeholders, and that there are handbooks with definitions for the different stakeholder groups. The issue is that there is no uniformity among the different handbooks, which makes generalization of different studies more difficult. Although it is always difficult to select relevant stakeholders for a study, this decision should be driven by the goal and scope of the analysis and by the financial, temporal and data resources available to the researchers. Researchers should aim to include as many stakeholders as possible in their study, given their constraints. Based on the expert feedback, this challenge will be kept.

6.4 Limitations of Expert Feedback Survey

One of the limitations of the survey feedback is the low number of participants. As previously mentioned, out of 38 requests, only 6 experts completed the expert feedback survey, resulting in a 16% completion rate. The low participation rate may be due to the lack of any previous exchange between the research team and the experts contacted. Even though the survey provided all the necessary contact information about the research team and an explanation of its purpose, it is believed that most of the experts were not interested in completing a survey received from a research team that they were not familiar with. Despite of the lower than desired participation rate, electronic surveys allow researchers to contact experts globally. It was desired to have as many participants as possible, which is why it would be recommended to establish some type of prior contact with the experts before sending the survey requests. Nonetheless, six participants are a significant sample size for experts, as they are notoriously difficult to access, and sample sizes in studies of experts across the literature are often in the single digits. An additional limitation of the expert feedback is that, even though all of them were familiar with Life Cycle Assessments, not all of them had experience performing social impact assessments. Although there are inherent similarities between social impact assessments and life cycle assessments, it would be of benefit if all experts providing feedback had first-hand experience performing SIAs. Given the two limitations of the expert survey feedback exercise, it is recommended to perform such a task in a setting where the experts are present, such as a workshop or a conference on the topic of SIA and have them provide the feedback in person.

6.5 Conclusions

Gathering expert feedback is beneficial in the development of a support tool, such as the novel SIA framework presented in this thesis. Because of the breadth of applications covered by SIAs, having feedback from experienced practitioners adds validity to the findings of the systematic mapping procedure. Out of the twelve challenges identified, seven were supported by the experts, four were supported but to a lesser degree, and one was not recognized as a challenge. These findings resulted in a reduction of the list of challenges from twelve to ten by the removal of Challenges #10 and #11. These results highlight the validity of the challenges identified during the systematic mapping procedure. The rest of the challenges were kept based on the expert feedback data. The next chapter presents the learnings of providing a simplified version of the novel SIA framework to capstone students. The methodology, results and key findings of this process are presented, as well as how the student feedback is used to modify the SIA framework.

CHAPTER 7 NOVEL SIA FRAMEWORK DEVELOPMENT: CAPSTONE FEEDBACK

7.1 Introduction

In Chapter 5, the importance of user feedback in the development of a design support tool is presented. Chapter 6 focuses in expert feedback, which provided valuable learnings regarding the validity of the identified challenges and input used to modify the framework. In this chapter, another user feedback exercise is presented based novice rather than expert feedback. The design of a proper framework should provide guidance to both experts and novice users, and its efficacy should be minimally influenced by the knowledge level of the user. In this chapter, the methodology used to gather novice user feedback from senior capstone design students is presented. The analysis of the gathered data is shown, along with the associated limitations and learning from the study. The feedback is used to enhance the simplified SIA framework provided to future students in the capstone design class. Student feedback is a crucial aspect of this thesis, as an important aim of the framework is to support the education of engineering students in assessing the potential social impacts of their design decisions.

7.2 Methodology

The novice user feedback study involved undergraduate senior capstone students from the Georgia Institute of Technology. The students were provided with a 50-minute lecture on the topic of SIA, along with an example of an S-LCA of a laptop computer. As part of the lecture, the students were also provided with a simplified version of the SIA framework that didn't include the impact assessment stage, which can be found in Appendix F. The impact assessment stage was removed for the novice users because of the time and data resources available to perform this step. For most of the students, the SIA lecture was the first time that they were introduced to the topic of social impacts, so performing a full SIA was deemed too overwhelming and time-intensive. Instead, the focus of the lecture and the exercise was to provide students with the knowledge to develop a complete plan to perform an SIA.

Three reference documents were provided to the students, two of which are provided in the Appendices of this dissertation: *simplified capstone SIA framework (Appendix F), SIA results template (Appendix G),* and the *2011 UNEP/SETAC Methodological Sheets for Sub-Categories in S-LCA* [22]. The simplified framework consists of the following three assessment stages: goal and scope, inventory analysis and interpretation of results. As previously stated, the impact assessment stage was removed. The capstone students were also provided with guiding questions during the interpretation of results stage of the assessment.

Once the lecture was delivered, feedback from the students was collected using two methods. The first was through a Qualtrics electronic survey (Appendix H), in which students provided feedback about the quality of support of the framework and its associated documents. The second method involved a qualitative assessment of the SIA reports provided by the students. The reports were assessed based on the following eight criteria: *evidence of social awareness, level of applicability to design project, accuracy and completeness of framework implementation, increased mastery of appropriate terminology and vocabulary in SIA, ability to be critical of their projects for the sake of improving* *social impacts, goal and scope explanation, inventory analysis explanation and interpretation of results explanation.* For each report, a qualitative score was given as either poor, acceptable or excellent. Table 30 shows the evaluation rubric that was developed and used in the qualitative assessment of the capstone student reports.

Table 30: SIA capstone report rubric for qualitative assessment

Capstone data processing criteria	Poor	Acceptable	Excellent
Evidence of social awareness	Students make minimal or no comments regarding the potential social impacts of their project	Students express social awareness about the potential social impacts of their project, but they don't follow (or partially follow) the instructions provided in the template	Students express social awareness of the potential impact of their project on the interpretation of the results; students used the template to answer the questions and provided responses that are thoughtful and substantive
Level of applicability to project	The project does not lend itself to perform a social impact assessment using the framework provided	The project allows for minimal application of steps provided in SIA framework; students talk about the limitations of their project in application of SIA framework	The project description allows student to apply SIA framework without any issues
Accuracy and completeness of framework implementation	Less than half of the SIA sections are shown or none of the templates or reference documents provided were used; data, if presented, is not organized in a logical manner	More than half of the sections are included; results are presented in a logical manner, but the reference templates and documents were only partially used	All the sections required by the SIA framework are included: the templates and reference documents are used throughout the analysis
Increased mastery of appropriate terminology/	Students do not use SIA related terms throughout the report	Although students use SIA terminology, they don't show a deep	SIA terminology is used throughout the report and are used in a logical manner

vocabulary in social impact assessment		understanding of the terms	
Ability to be critical of their own projects for the sake of improving social impacts	No criticism is done about how decisions of the project could result in social impacts	Students provide explanations about the potential social impacts of their project and make reference to the stakeholder groups being affected	Students refer back to the results of their analysis to explain the potential social impacts of their project; they provide directions and recommendations for how to reduce the potential social impacts of their design in future applications
Goal and scope explanation	Goal and scope reference table is not used to organize the results; no definitions of the goal and scope of the analysis are provided	Although the reference documents and templates are used, no explanations or a poor explanation of the goal and scope are provided	Goal and scope of the analysis are provided along with a justification of the focus of the analysis; the selected product lifecycle stages are identified
Inventory analysis explanation	Reference documents and templates were not used; students don't use the term inventory analysis at all in their explanation	Although reference table and documents are used, no justification for selection of indicators, social impacts categories and/or stakeholders is provided	Explanations are provided for the selection of the social impact categories, indicators; evidence of external search to support the information of the reference documents
Interpretation of results explanation	No interpretation of the results is provided; the guiding questions from the template are not used	An interpretation of the results is provided; students talk about the potential social impacts of the design, and they reference those back to their selection of the lifecycle stages and stakeholder groups; no recommendations are made to prevent	An interpretation of the results is provided; the students address at least all the guiding questions provided in the template; recommendations are provided for how to prevent potential impacts in future design iterations

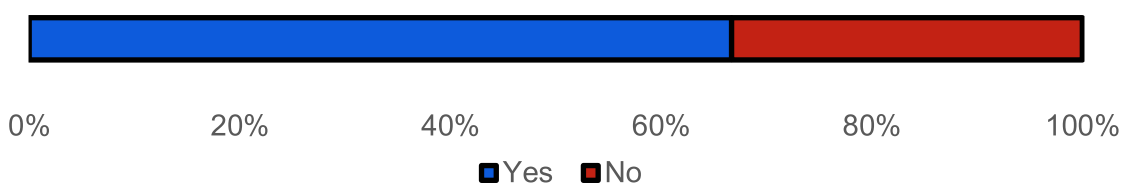
		potential impacts in future design iterations	

7.3 Analysis of Results

7.3.1 Electronic survey feedback

A total of six students completed the electronic feedback survey for the SIA framework. Results are provided for each question along with an overall statement.

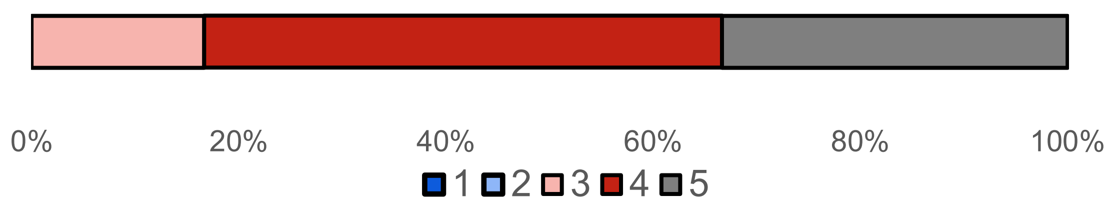
Question #1: Is the social impact assessment applicable to your project?



Option	Answers
Yes	4
No	2

Although SIA are expected to be applicable to all design projects, the SIA exercise for their capstone report intends to assess their understanding of the applicability of SIA to their capstone design project. Surprisingly, some students felt that the SIA framework was not applicable to their project. Overall, the majority of the students agreed that SIA was applicable to their project, as expected.

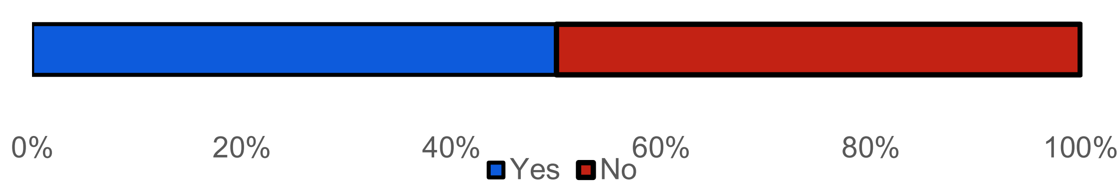
Question #2: How important is it to consider social impacts in the design process?



Option	Answers
1-Not important	0
2	0
3	1
4	3
5-Very important	2

Most students agreed that it is important to consider social impacts in the design process. Perhaps some students believe that the functionality, economic feasibility and technical details of the product are of more importance, due to the emphasis placed on these aspects throughout the undergraduate engineering curriculum. However, this is just conjecture, as the students were not asked about the relative importance of other aspects of the design.

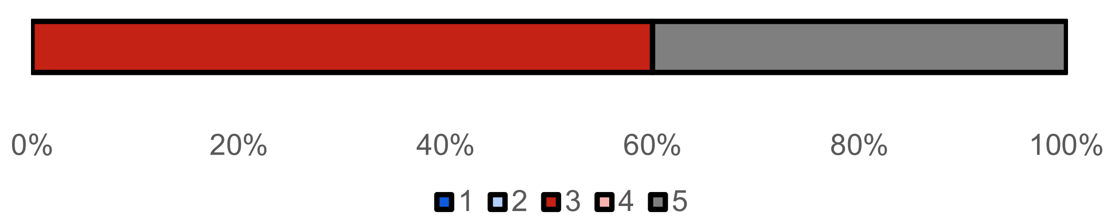
Question #3: Would you have considered social impacts in your design project before this course?



Option	Answers
Yes	3
No	3

Half of the students admitted to not having considered social impacts as part of the design problem before the SIA lecture. It is observed that half of the students would have considered social impacts as part of the design problem, which raises the following question: what social impacts would they have considered? This is a question worth investigating in a future feedback exercise, preferably with a controlled study to see what type of impacts students are categorizing as social impacts, and how this perception changes after being given a formal lecture in SIA.

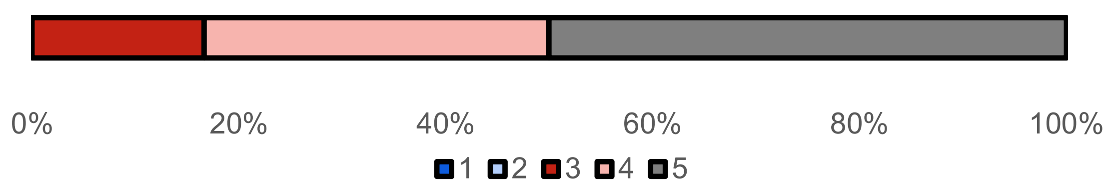
Question #4: How helpful was the social impact assessment framework in organizing the steps to perform it?



Option	Answers
1-Not helpful	0
2	0
3	3
4	0
5-Very helpful	2

The students provided neutral to positive responses for this question. Although it seems that the framework helped the students in this capstone section, there is definitely room for improvement, as most of the students expressed that it was neutral - not helpful nor unhelpful. One possible improvement to the framework would be to provide students with the list of challenges identified in the systematic mapping process. Even though not all of the challenges are present in the simplified framework because of the removal of the impact assessment stage, the students would still face challenges related to the selection of social indicators, selection of relevant stakeholder groups, and even the definition of the system boundaries. The challenges can be mapped to the each of the assessment steps in the simplified SIA framework along with methods available to aid in overcoming each of these challenges. Another possible change to the framework would be to include portions of previous capstone reports that had a rating of excellent in the different criteria, so that students have a better idea of what is expected in the reports, in addition to providing the instructions in the outline. This would also prevent students from delivering incomplete SIA results, which happened more than once during the qualitative assessment procedure. Most of the capstone students struggled in the interpretation of results stages, specifically when asked to provide recommendations for changes to reduce the potential social impacts of future design iterations. Even though an example was provided, perhaps additional examples that are applicable to different types of capstone design problems should be provided. A portion of the electronic survey asked for open-ended feedback regarding the use of the framework, to which only one student provided the following answer: "It felt arbitrary and didn't help much. In the lecture, not much time was given to actually practice the techniques." Based on this feedback, the SIA lecture itself should be modified to explain in more detail to the students the structure of the framework and to provide more time for the students to practice the techniques during lecture time. Even though in-class exercises were performed, it might be feasible to use two, 50-minute lectures instead of a single one. The first lecture could be devoted to explaining the SIA theory and framework. The second lecture could instruct upon the application of the techniques in an in-class exercise, during which the students have the chance to work on the problems as a group and can ask the instructors for feedback on their progress.

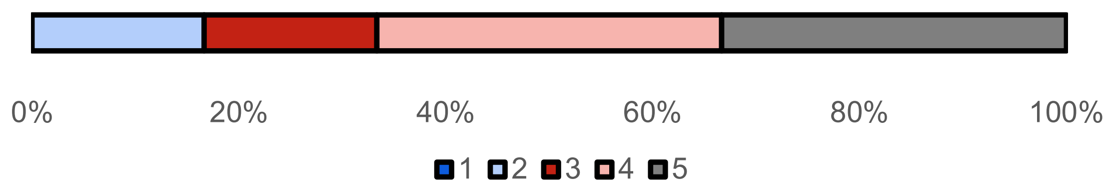
Question #5: How helpful were the examples provided in the social impact assessment framework?



Option	Answers
1-Not helpful	0
2	0
3	1
4	2
5-Very helpful	3

The examples provided in the reference documents were considered helpful by the students. Relative to economic and environmental assessments, the range of disciplines in which SIAs are applied is extensive. This is why a considerate effort was put into providing numerous and varied example applications. The aim was to show students the universal application of SIAs. Still, it might be of value to use capstone design problems from past cohorts to populate future examples in the reference documents.

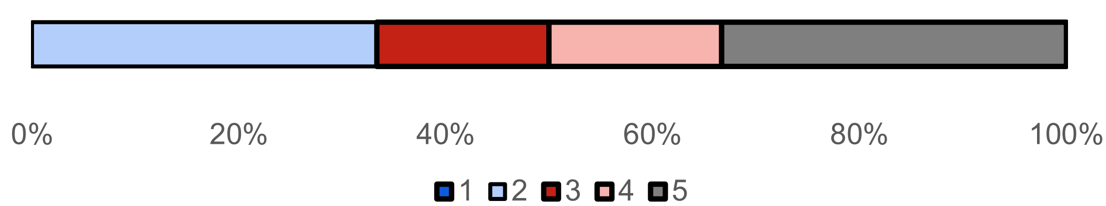
Question #6: How helpful was the social impact assessment framework for organizing your analysis/results?



Option	Answers
1-Not helpful	0
2	1
3	1
4	2
5-Very helpful	2

Although there were mixed reviews, most of the students expressed that the framework support was helpful. It must be considered that for most of these students, it is probably the first time that they heard the term "social impacts", so asking them to perform an SIA for their capstone report was probably a challenge. Even though the framework provided support, there are still ways to improve it, which will be guided by using this input and the input from the capstone report qualitative assessment.

Question #7: How much did it help to determine which stakeholders are impacted more?



Option	Answers
1-Not helpful	0
2	2
3	1
4	1
5-Very helpful	2

The results provide mixed reviews for this question. It is known that, even for experts in SIA, the selection of relevant stakeholders is a significant challenge. Perhaps the simplified version of the framework should include more detailed guidance regarding the selection of relevant stakeholders for the analysis. Still, most of the students agreed that the framework provides support in the selection of the relevant stakeholders.

7.3.2 Capstone report qualitative assessment

The capstone report sections on SIA were assessed for seven capstone student groups. The reports were assessed based on the rubric shown in Table 30. Table 31 shows the number of reports that were given each of the rubric scores for each criterion. The criteria used for the qualitative evaluation aims to capture the ability of the student teams to apply the provided reference template and reference documents, and to thoroughly explain the importance of each assessment stage of the SIA. By doing this qualitative assessment, it is expected to identify the areas in which the students excelled, but more importantly, the areas in which the framework should be enhanced. Overall, most of the teams received an acceptable or excellent score in most of the criteria, which is encouraging. Quotes extracted from the highest quality reports are provided for each of the criteria being evaluated. Portions of the quote related to details of the design are removed to prevent identification of the capstone projects and subsequently of the capstone team participants in the study.

Table 31: Qualitative assessment summary for capstone SIA reports

#	Capstone Data Processing Criteria	Number of reports with the given score		
		Poor	**Acceptable**	**Excellent**
1	Evidence of social awareness	3	2	2
2	Level of applicability to project	0	0	7
3	Accuracy and completeness of framework implementation	3	3	1
4	Increased mastery of appropriate terminology and vocabulary in social impact assessment	3	1	3
5	Ability to be candid and critical of their own projects for the sake of improving social impacts	2	3	2
6	Goal and scope explanation	3	0	4
7	Inventory analysis explanation	3	1	3
8	Interpretation of results explanation	3	3	1

Regarding criteria #1 "evidence of social awareness", the majority of the student teams provided an acceptable description of the potential social aspects of their design. The student teams did a great job of mapping the possible potential impacts to each of the stakeholder groups and the product lifecycle stages. Some reports showed evidence of external research data and references, in addition to the reference documents provided, which shows increased interest and commitment. The following quote is from a report that had an excellent rating in criteria #1: "Associated with the production cycle, it is important to evaluate the methods in which the workers are affected. Workers are impacted by health and safety concerns associated with the use of PET, both with the sanitation concerns associated with used bottles and the extraction of the recyclable materials themselves both of which should be regulated under FDA standards." The students make a great point in highlighting an area of concern in the process, which could be the focus of efforts to minimize impacts on workers. The reports that did poorly in this section either didn't make any social awareness comments at all, or if they did, the comments were not mapped to any of the product lifecycle stages or the stakeholder groups.

Criteria #2 “level of applicability of the project” showed excellent performance, which is expected as SIA are deemed to be universally applicable. Even though the simplified SIA framework is applicable to all the capstone design projects shown in the evaluated reports, it is does not mean that it will be seen as applicable to the capstone projects of all students in the course. The SIA framework is expected to be applicable to all projects, but because only six reports were reviewed in this qualitative assessment section, such a statement is made. Still, it is encouraging to see that for all the reports analysed for these criteria, the SIA framework is applicable.

Criteria #3 “Accuracy and completeness of framework implementation” shows more of an acceptable rather than excellent level of completion. The reports that had a score of excellent, provided all of the information asked for in the guiding documents and provided explanations for that information. Quotes or tables from those reports are not included here because they show specifics about the design projects, and this may allow readers to identify the students working in those groups. Reports that had an acceptable score used the templates and guiding documents provided to develop the reports, but they failed in the interpretation of results assessment stage. For this stage, guiding questions were provided, and only one of the groups answered all of the guiding questions. The reports that were given a score of poor either didn't use the provided templates or just placed information in the templates without any supporting explanation.

Criteria #4 “Increased mastery of appropriate terminology and vocabulary in social impact assessment”, aimed at evaluating the use of LCA and SIA terminology in the explanation provided by the students. Most of the reports used terms such as product lifecycle stages, stakeholder groups, social impact categories and social impact indicators in their explanations. The following is a quote from a report that used SIA and LCA terms extensively throughout their explanations: “After selecting applicable lifecycle stages for the device, the Methodological Sheets for Sub-Categories in the Social Life Cycle Assessment were utilized to determine stakeholders involved in each stage… For each stakeholder there are social impact categories that affect that specific stakeholder. Within those categories are impact indicators that measure positive and negative societal impacts.” Here the students referred to the methodological sheets, they used the terms “stakeholders”, “impact categories” and “impact indicators”, which is what is expected. The reports that received a score of poor either didn’t use any of the terms or didn’t use the reference documents provided, which make extensive use of the terms. These reports were probably from groups that didn’t attend the SIA lecture explanation, but this is merely a speculation and must be investigated in more detail.

Criteria #5 “Ability to be candid and critical of their own projects for the sake of improving social impacts”, aimed at assessing the ability of the students to foresee the potential social impacts of their designs in an honest way. This is a very important part of the SIA, as it requires the students to research the far-reaching impacts of their designs. Most of the reports received a score of either acceptable or excellent because they completed the templates for the goal and scope, and the inventory analysis sections. These two sections require the students to select and justify the selection of the affected stakeholder groups and possible social impacts upon them. The following quote is from a report that highlights potential impacts of the proposed product: “If the…supplying company exploits workers, uses child labor, or overworks their employees in order to meet the increased demand for…, then the effects will be negative…A negative societal impact is that new system reduces the slowdown periods, which means that the system will feed more…overall, and thus more…will be produced. This will cause more waste when the …are thrown away at the end of life cycle stage.” This group presents the possible negative social impacts resulting from the design and maps those potential impacts to stakeholder groups and lifecycle stages. The groups that received a score of excellent in these criteria mapped the selected social impact categories and indicators to the respective stakeholder groups and product lifecycles, while also providing justification for their selections. Reports that received a poor score either did not mention any possible social impacts resulting from their designs, or mostly referred to environmental impacts.

Criteria #6 “Goal and scope explanation” refers to the first SIA stage. Out of all the criteria evaluated, this one had the most polarized results, with no teams in the acceptable columns and all of them receiving either an excellent or poor score. In addition to using the provided template, those reports that received a score of excellent, clearly defined the goal and scope of their analysis and provide justification for the definition. These reports clearly defined the subsystems being analyzed and used the goal and scope definition to guide the rest of the assessment. The following are quotes from reports that did excellent in this criterion: “The…reduces paper waste and line slowdown periods, and the new system also brings changes to how the worker interacts with the line. The social impact assessment focuses on the effects of these changes.” This report clearly defines the goal and scope of the SIA being proposed. “The functional units being considered are the…and …of product. This is associated with the production, manufacturing, and end of life stages, shown in Table ….” Here the students clearly defined the functional unit of the analysis and defined the lifecycle stages included in the analysis. Those reports that received a score of poor either didn’t use the provided templates, or if used, no explanation of justification was provided for the information provided.

Criteria #7 “Inventory analysis explanation” refers to the second SIA stage. Most of the reports received either a score of acceptable or excellent. These reports used the provided template and reference documents to present the social impact categories and indicators relevant in the analysis. The reports that were given a score of excellent, provided an explanation for the social impacts categories and indicators selected, and in some instances, provided sources supplemental information for their analysis. The following quote from a student team report clearly defines the stakeholder groups considered in the analysis and the processes that guide the selection of the impact indicators: “Stakeholders being considered in this assessment are workers, society, the local community, and value-chain actors…. Impact indicators include examining existing protocols, looking at the number of injuries over a period of time, and analyzing OSHA violations that occur that have not yet caused injuries, but could in the future. Value-chain actors are assessed to determine the effects of outsourcing labor, and indicators involve methods to ensure that…outsources their labor from reputable companies, shown in Table …The local community is assessed to determine how…(the) new process will affect local employment, with indicators analyzing how their employment demographics change over time.” The reports that were given a score of poor, either did not use the provided templates to organize the information requested in this section, or if the information was provided, no explanation or justification was provided.

Criteria #8 “Interpretation of results explanation”, is the third and final stage of the SIA. This section is clearly the most challenging for the students, as only one team had a score of excellent, and the majority of scores were acceptable and poor. In the template, the students were given guiding questions to aid in this section of the report. At a minimum, the students were expected to answer all the questions listed. The following quote is from the group that received an excellent score in this criterion: “For the consumers, the disassembly and disposal process present the possibility for injury through mishandling, and potentially breaking parts of the product. This concern will be addressed with comprehensive disassembly instructions and the product will be designed so that as few steps as possible will be needed to disassemble the product.” In the report, the students highlight the potential impacts of the use of their product and the affected stakeholder groups. They also propose solutions to minimize the mentioned health and safety social impacts in future design iterations. In those reports that were given a score of acceptable, the students did answer some of the guiding questions, but they failed to address in detail what future changes should be made to the design of the product to reduce future social impacts. The reports that were given a score of poor either didn’t complete this section or did not address the guiding questions in their analysis.

For those student teams that followed the guidance provided in the reference documents, the SIA results provided the expected information about the potential impacts of the proposed designs, about the relevant product lifecycle stages and stakeholder groups, and about what future design changes could reduce such impacts. Although there were a number of groups that did not use the provided templates to organize the information, this is likely due to a communication issue rather than an issue with the framework itself. Attending capstone lectures is not required for students, and as the semester gets more difficult, student attendance to capstone lectures tends to vary more significantly. This is the reason why some of the students did not attend the SIA lecture. Another important aspect to consider is the variation in the capstone instructor perception about the importance of the social impact section. Although most instructors support and value SIA as part of the capstone course, there are some instructors that did not promote this procedure in their capstone section, which might explain why some reports did not complete the section at all. Still, the feedback from the electronic surveys and the qualitative assessment helped identify changes that should be made to the simplified version of the SIA framework.

An important observation from the qualitative assessment of the reports is that most of the students performed the SIA on the final design or during the detailed design of their project. It would be beneficial for students to start considering social impacts at earlier stages of their design process; thus, one recommended change would involve adding methods in the reference documents that help students with the evaluation of social impacts at earlier design stages of their capstone project. Examples could include house of quality applications that include social criteria in the analysis, or matrix evaluation methods that incorporate social impact criteria when comparing product concepts. The goal here is to show students how methodologies used in earlier design courses of their engineering can incorporate social aspects when selecting the best overall design to develop. The framework should allow the students to perform the analysis at such stages where there is less available information about the product. The second change involves the guidance in the interpretation of the results section. This is the section of the assessment that seemed to be most challenging to all students, even those that did an excellent job with the rest of the report. The changes would involve adding guidance that aids the students in determining possible design changes to future iterations of the product. This could either involve additional questions or providing examples that the students can use as a guide. The third change would be to make sure that the students separate environmental and social impacts in their analysis. Although it is recognized that there would be inherent connections among these two types of impacts, the students should focus on explaining such an understanding in the interpretation of the results. A lot of the reports showed students focusing only on environmental impacts, but it is expected that they focus more on the social impacts for this section of their report. In addition to these framework changes, it is recommended that attendance is taken during the SIA lecture. The purpose of this would be to see if the students that did not do any portion of the SIA analysis, or that did not use the templates provided, never actually attended the lecture and only relied in the reference documents available to them electronically.

7.4 Limitations of capstone student feedback

The capstone student feedback study had numerous limitations. One limitation is that this is not a controlled study. Ideally, two different groups of students would be given the tasks to complete an SIA, where one group is given access to the framework and one is not. By comparing the two groups, conclusions about the efficacy of the framework can be drawn. Another limitation is the low participation rate of the students. Because of such a low number of participants, no generalizations or statistical analyses of the results can be made for the rest of the senior capstone student population. An additional limitation relates to the qualitative assessment of the student reports. This exercise was done by a single coder. Ideally, multiple coders would be used to perform such an analysis. An interrater agreement analysis would then be performed to identify agreement among the different coders and to address any disagreement. This approach reduces coding bias and improper assessment. The last limitation of the capstone feedback study is the fact that there is no record of the number of students that didn't attend the SIA lecture. This may be important when performing the qualitative assessment of the reports because it may be that the students that did better on the report attended the SIA lecture relative to those that didn't attend it. It may be that the reference materials might not be enough for the students to know in detail what is expected from them in the SIA report section. Also, there was one team that didn't complete an SIA section at all. This might reveal some miscommunication issues regarding the requirements of the capstone report that should be investigated for future instances.

7.5 Conclusions

Providing adequate novice user support is essential to improving the quality of SIA. One goal of the novel SIA framework developed in this thesis is for it to be useful for both novice and expert users. The novice user feedback collected in this chapter aims at complementing the expert feedback gathered and shown in Chapter 6 of this thesis. The novice user feedback highlighted areas in which the framework should be enhanced to make it more useful in a classroom setting. Overall, the student feedback on the framework was positive. The qualitative assessment revealed that the most challenging part of the assessment is the interpretation of results stage. Future versions of the framework will provide students with additional guidance in this section, with a focus on how to determine potential changes to the product design that would reduce the social impacts of future design iterations. Another observation is that all of the groups performed the SIA on the final design iteration. For future SIA capstone lectures, the students would be advised to consider social criteria at earlier design stages, and they should be provided with an even simpler version of the framework for such purposes. In addition, the qualitative assessment clearly revealed the difference between students that followed and those that did not follow the guiding templates. The quality of the report of the students that followed the provided instructions was far superior to those that did not use the reference documents provided. In the future, a controlled study between two groups of students, one group with access to the SIA framework and another without access to the SIA framework, should be performed to evaluate the efficacy of the framework support. The learnings from the novice user feedback study will be incorporated into the guiding templates and documents provided to future capstone students. The goal is to provide future engineers with a basic understanding of social impacts and the tools available to systematically assess the social impacts of design decisions.

The combination of the expert and novice user feedback now leads to the case study feedback exercise presented in the next chapter. Incorporating the case study feedback is the final step of the framework evaluation plan, and will result in the finalized version of the novel SIA framework.

CHAPTER 8 NOVEL SIA FRAMEWORK AND CASE STUDY TESTING: SIA OF ROOFTOP SOLAR PANELS

8.1 Introduction

As stated in Blessing et al. [30], “the term case study is used to describe a study that involves data from a real setting and is seen as equivalent to an observational study in which only one or very few cases are involved.” In this study, case study testing is used for numerous reasons. It is first used to identify whether novel SIA framework can be used to achieve the intended results, whether the framework contributes to success for the user, and to identify necessary improvements to the concept of the framework. Second, it is used to inform changes to be made to the novel SIA framework for improvement. In this chapter, the case study process is presented in detail. An application of the novel SIA framework is presented in detail, along with the results and learnings, and the limitations identified in the framework. The limitations are key as they inform the recommended next steps in the framework development process and future research directions.

8.1.1 Rooftop solar panel case study

The case study presented in this chapter involves the application of the novel framework to perform a social impact assessment of a rooftop solar panel. The rooftop solar panel technology was chosen for two reasons. First, while rooftop solar panels are seen as a promising technology to reduce CO_2 emissions, they involve the use electronic components and rare resources that are environmentally harmful. Second, the case study was facilitated by a collaboration with the Georgia Drawdown Project from the Ray C.

Anderson Foundation [184]. The Georgia Drawdown Project aims to identify the most promising solutions for achieving carbon neutrality in the state of Georgia. The project has six areas of focus: *electricity generation, transportation, built environment, food, and land use*. Focusing on the electricity generation category, rooftop solar panels are one of the options being considered. The aim was to use the solar rooftop panel as a case study to test the novel SIA framework and provide the results of the study to the Georgia Drawdown Project team, while also achieving the objectives of the DS-II study stage.

8.2 SIA Case Study Results

To perform the analysis, an excel worksheet was created where the analysis for each of the assessment stages is done. Also, a database of indicators and methodologies is incorporated in the worksheet.

8.2.1 Goal and Scope

This first step of the framework aims to describe the study why the study is being perform and what is included in the analysis. The decisions made at this stage of the analysis are important because they have a profound effect on the rest of the analysis.

Table 32: Goal and scope information for rooftop solar panel case study

Define the goal/objective of the study	
What is the study objective?	Evaluate the social impacts of rooftop solar panels installed per individual house
Are processes considered?	Processes that involve the end of life treatment of the solar panels are considered
Evaluation of company conduct	Although companies are part of the process of installing and managing the end of life phases of the solar panels, this analysis is too early to be evaluating company conduct; the analysis is focused only on the technology

Level of Detail	Low detail analysis is performed at first, and then a more detailed analysis will be performed based on the results of the low detail study
Study timing	Pre-implementation; the technology has not yet been implemented
Reason for study	Inform the audience about the social impacts of the rooftop technology; other energy generation technologies are being considered, but the analysis is starting with rooftop solar. The audience are LCA experts and sustainable energy technology experts.
Single or multiple products?	Single product
Define the product functionality	Generate electricity using incoming solar irradiation
Define the scope of the study	
Spatial scale of analysis	National (United States) and Regional (State)
Analysis type	Informative
Initial system boundaries	
Lifecycle stages considered	Use Phase; End of Life Phase
Associated activities	Product Use, Product Maintenance
	Disposal method of solar panel
Stakeholder groups considered	Consumers, Local community, Society, Workers
Functional unit	1 kWh

Table 32 shows goal and scope information for the rooftop solar panel case study. The aim of the case study is to inform technology decision makers, who include policy makers and the Georgia Drawdown Project experts, about potential social impacts of such a technology. The analysis is performed before any of the rooftop solar panels are implemented, which means that company conduct is not considered in the analysis. The focus of the study is on the technology itself, rather than on the conduct of companies involved. Because the technology is evaluated to be used in the state of Georgia, only the use and end of life lifecycle stages are considered of importance in the analysis. The team decided to first focus on these two stages and to then perform a more detailed analysis of all the stages in the lifecycle. The stakeholder groups considered in the analysis are the consumers, the local community, society and the workers. The functional unit for the analysis is one solar rooftop panel.

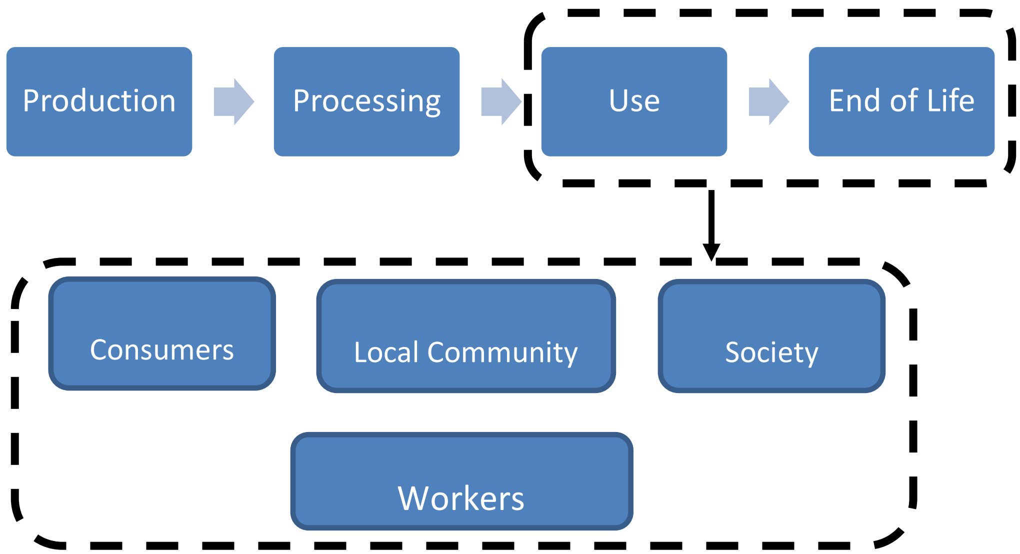


Figure 15: Initial system boundaries defined for rooftop solar panel assessment.

Figure 15 shows the definition of the system boundaries for the analysis: the use and end of life phases are considered, and all stakeholder groups except for the value-chain actors are considered in the analysis.

8.2.2 Inventory Analysis

In the inventory analysis stage the data that is used to perform the social impact assessment by means of the selection of the indicators used in the analysis is presented. The steps followed to populate the list of indicators used in the analysis are presented in detail in chapter 5 of this thesis. When referring to the indicator database, a total of 58 indicators are selected for the analysis based on the relevance to the goal and scope of the analysis. After two additional revisions, the list of indicators was reduced to 24, based on indicators that were found to be out of scope of the analysis and based on indicators that are expressed differently in the source documents but measure the same social aspect. This is why it is recommended to perform multiple revisions of the indicator list in to obtain a concise list. Table 33 shows the final set of indicators.

Table 33: Selected list of indicators based on analysis goal and scope

#	Name	Type	Impact Category	Stakeholder Group	Desired Direction or Answer
1	Child labor involvement in any lifecycle activity	Semi-quantitative (Yes/No)	Child labor	Workers	No
2	Community trust/approval in technology risk information	Semi-quantitative Likert Scale	Participation and influence	Local community	Positive
3	Contribution of the technology to economic progress	Quantitative	Contribution to economic development	Society	Positive
4	Energy security	Quantitative	Social acceptance and societal impacts	Society	Positive
5	Existence of government regulation on public sustainability reporting for technology	Semi-quantitative (Yes/No)	Public commitment to sustainability issues	Society	Yes
6	Health hazard from emissions during any lifecycle activity	Semi-quantitative Likert Scale	Health and safety	Workers	Negative
7	Income inequalities	Quantitative	Equality	Society	Negative
8	Level of material resource use due to product design decisions	Semi-quantitative Likert Scale	Access to material resources	Local community	Negative
9	Number of individuals involuntarily relocating due to technology implementation	Semi-quantitative (yes/no)	Delocalization and migration	Local community	No
10	Occupational health and safety	Quantitative	Health and safety	Workers	Negative
11	Possibility of technology components to be reused for other purposes	Semi-quantitative Likert Scale	End of life responsibility (Options)	Consumer	Positive

12	Potential of technology to affect health and safety of workers during the end of life phase	Semi-quantitative (Likert Scale)	Health and safety	Workers	Negative
13	Presence and quality of infrastructure to dispose responsibly of product components	Semi-quantitative Likert scale	End of life responsibility (Options)	Consumer	Positive
14	Presence and quality of programs to assist in citizens with high energy burdens if technology is implemented	Semi-quantitative (yes/no)	Equity	Society	Yes
15	Presence of public agreement to sustainability using the selected technology	Semi-quantitative (Yes/No)	Public commitment to sustainability issues	Society	Yes
16	Product design or technology design makes use of local resources and expertise	Semi-quantitative (Yes/No)	Local employment	Local community	Yes
17	Protests to the proposed technology	Semi-quantitative (Likert Scale)	Protest	Local community	Negative
18	Extent to which the technology negatively affects the local community's sense of place and cultural heritage	Semi-quantitative (Yes/No)	Cultural heritage	Local community	No
19	Spatial equity of technology: a fair distribution of risks and costs throughout the territory	Semi-quantitative (Likert Scale)	Equality, equal opportunities	Local community	Positive
20	Technology is not expected to increase energy burden	Semi-quantitative (Likert Scale)	Inclusiveness	Consumer	Positive
21	There is evidence that the product is safer than other products used for the same purpose	Semi-quantitative (Likert Scale)	Health and safety	Consumer	Positive

22	Do electricity consumers have a choice in the utility company that will be in charge of the technology?	Semi-quantitative (yes/no)	Fair competition	Consumer	Yes
23	Are the community members likely to be displaced by a different population group?	Semi-quantitative (yes/no)	Equality	Consumer	No
24	Is the technology used accessible and affordable to developing countries?	Semi-quantitative (Likert Scale)	Technology transfer, access to immaterial resources	Local community	Positive

Table 34: Data quality assessment results for indicators used in rooftop solar panel assessment.

#	Indicator name	Accuracy, integrity and validity	Timeliness	Geographical correlation	Technological correlation	Data quality score
1	Child labor involvement in any lifecycle activity	3	3	1	2	2.3
2	Community trust/approval in technology risk information	2	1	1	1	1.3
3	Contribution of the technology to economic progress	1	1	2	1	1.3
4	Energy security	1	1	1	1	1.0
5	Existence of government regulation on public sustainability reporting for technology	1	3	2	1	1.8
6	Health hazard from emissions during any lifecycle activity	3	2	2	1	2.0
7	Income inequalities	1	1	1	1	1.0
8	Level of material resource use due to product design decisions	1	3	2	1	1.8
9	Number of individuals involuntarily relocating due to technology implementation (Gentrification)	2	2	3	1	2.0
10	Occupational health and safety	1	1	1	1	1.0

11	Possibility of technology components to be reused for other purposes	1	1	3	1	1.5
12	Potential of technology to affect health and safety of workers during the end of life phase	1	3	2	1	1.8
13	Presence and quality of infrastructure to dispose responsibly of product components	2	2	2	1	1.8
14	Presence and quality of programs to assist in citizens with high energy burdens if technology is implemented	3	2	2	1	2.0
15	Presence of public agreement to sustainability using the selected technology	1	2	1	1	1.3
16	Product design or technology design makes use of local resources and expertise	2	1	1	1	1.3
17	Protests to the proposed technology	2	3	1	1	1.8
18	Extent to which the technology negatively affects the local community’s sense of place and cultural heritage	3	2	2	1	2.0
19	Spatial equity of technology: a fair distribution of risks and costs throughout the territory	1	2	2	1	1.5
20	Technology is not expected to increase energy burden	3	2	2	1	2.0

21	There is evidence that the product is safer than other products used for the same purpose	2	2	1	1	1.5
22	Do electricity consumers have a choice in the utility company that will be in charge of the technology?	3	2	3	1	2.3
23	Is the percentage of the local community expected to be displaced different by population group in the area?	2	3	3	1	2.3
24	Is the technology used accessible and affordable to developing countries?	3	2	2	1	2.0

In this case study, the data quality assessment was performed by a single researcher. However, best practice recommends performing the analysis independently among a group of researchers and corroborate agreement among the different quality criteria assessments. Table 34 shows the results of the data quality assessment. Because all average values are less than 3, no indicators were removed from the list due to poor data quality.

8.2.3 Impact Assessment

The first step in the impact assessment stage is to define performance reference points (PRP) for the quantitative indicators. PRPs are threshold values used to provide meaning to the quantitative data. They provide a reference from which to quantify the impact of the quantitative indicators. For this analysis, 4 out of the 24 indicators are quantitative.

Table 35: Performance reference points (PRPs) for quantitative indicators.

#	Name	PRP criteria	Scale	PRP calculation	Source
3	Contribution of the technology to economic progress	Power generation employment by industry	National	Normalized value of solar industry over range	2019 United States Energy and Employment Report [185]
5	Energy security (Percentage of domestic/locally sourced fuel) Irradiation levels for Georgia	Average 2018 direct horizontal irradiance value for continental US states	State	Normalized value of solar irradiance in Atlanta maximum range in continental US	2018 National Solar Radiation Database Direct Horizontal Irradiance Values [186]
9	Income inequalities (Gini coefficient)	Gini coefficient value for US states	State	Normalized value of Georgia over range for all states and territories	2017 United States Census Gini Coefficient Values [187]
13	Occupational health and safety (measure by accidents)	Deaths per TWh for us energy industries	Sector	Normalized value of solar industry over range	Death per TWh for energy industries [188]

Table 35 provides a summary of the PRPs used to characterize the quantitative indicators in the analysis. Table 36 shows the normalized indicator values for each of the indicators. No weighting scheme is applied to the case study analysis due to the following reasons. Weighting is not recommended for screening studies, such as the rooftop solar panel case study, because their objective is to provide an initial understanding of the system being studied using secondary data. Weighting is recommended at more detailed stages of the analysis where there is access to primary data from stakeholders or experts that can be used to justify the weighting values.

Table 36: Non-normalized and normalized values for rooftop solar panel SIA.

#	Stakeholder Group	Social Impact Subcategory	Indicator Name	Indicator Type	Scale	Desired Direction	Indicator Value	Units	Final Value
1	Workers	Child labor	Child labor involvement in any lifecycle activity	Semi-quantitative (yes/no)	Product or technology, national, international	No	No	Dimensionless	0
2	Local community	Participation and influence	Community trust/approval in technology risk information	Semi-quantitative Likert scale	Product or technology, sector, regional	Positive	5	Dimensionless	1
3	Society	Contribution to economic development	Contribution of the technology to economic progress	Quantitative	Product or technology, sector, regional, national	Positive	149343	Number of jobs in power generation industry	0.694
4	Society	Social acceptance and societal impacts	Energy security	Quantitative	Region	Positive	0.55	Average 2018 direct horizontal irradiance value for continental us states	0.550
5	Society	Public commitment to sustainability issues	Existence of government regulation on public sustainability reporting for technology	Semi-quantitative (yes/no)	Sector, regional or national	Yes	No	Dimensionless	0
6	Workers	Health and safety	Health hazard from emissions during any lifecycle activity	Semi-quantitative Likert scale	Product or technology	Negative	5	Dimensionless	0
7	Society	Equality	Income inequalities	Quantitative	Regional	Negative	0.489	Gini coefficient (dimensionless)	0.459
8	Local community	Access to material resources	Level of material resource use due to product design decisions	Semi-quantitative Likert scale	Product or technology	Negative	5	Dimensionless	0

9	Local community	Delocalization and migration	Number of individuals involuntarily relocating due to technology implementation (gentrification)	Semi-quantitative (yes/no)	Product or technology, sector, regional	Negative	Yes	Dimensionless	1
10	Workers	Health and safety	Occupational health and safety	Quantitative	Product or technology	Negative	0.44	Deaths per TWh for us energy industries	0.0111
11	Consumer	End of life responsibility (options)	Possibility of technology components to be reused for other purposes	Semi-quantitative Likert scale	Product or technology	Positive	5	Dimensionless	1
12	Workers	Health and safety	Potential of technology to affect health and safety of workers during the end of life phase	Semi-quantitative (Likert scale)	Product or technology	Negative	5	Dimensionless	0
13	Consumer	End of life responsibility (options)	Presence and quality of infrastructure to dispose responsibly of product components	Semi-quantitative Likert scale	Sector, regional or national	Positive	3	Dimensionless	0.5
14	Society	Equity	Presence and quality of programs to assist in citizens with high energy burdens if technology is implemented	Semi-quantitative (yes/no)	Sector, regional or national	Yes	Yes	Dimensionless	1
15	Society	Public commitment to sustainability issues	Presence of public agreement to sustainability using the selected technology	Semi-quantitative (yes/no)	Product or technology, regional	Yes	Yes	Dimensionless	1
16	Local community	Local employment	Product design or technology design makes use of local resources and expertise	Semi-quantitative (yes/no)	Product or technology	Yes	Yes	Dimensionless	1

17	Local community	Protest	Protests to the proposed technology	Semi-quantitative (Likert scale)	Regional, national	Negative	No	Dimensionless	1
18	Local community	Cultural heritage	Extent to which the technology negatively affects the local community’s sense of place and cultural heritage	Semi-quantitative (yes/no)	Product or technology	Negative	No	Dimensionless	0
19	Local community	Equality, equal opportunities	Spatial equity of technology: a fair distribution of risks and costs throughout the territory	Semi-quantitative (Likert scale)	Product or technology, sector, regional	Positive	3	Dimensionless	0.5
20	Consumer	Inclusiveness	Technology is not expected to increase energy burden	Semi-quantitative (Likert scale)	Product or technology	Positive	4	Dimensionless	0.75
21	Consumer	Health and safety	There is evidence that the product is safer than other products used for the same purpose	Semi-quantitative (Likert scale)	Product or technology	Positive	4	Dimensionless	0.75
22	Consumer	Fair competition	Do electricity consumers have a choice in the utility company that will be in charge of the technology?	Semi-quantitative (yes/no)	Product or technology, sector, regional	Yes	No	Dimensionless	0
23	Local community	Equality	Is the percentage of the local community expected to be displaced different by population group in the area?	Semi-quantitative (yes/no)	Regional	No	No	Dimensionless	0
24	Local community	Technology transfer, access to immaterial resources	Is the technology used accessible and affordable to developing countries?	Semi-quantitative (Likert scale)	Product or technology	Positive	3	Dimensionless	0.5

8.2.4 Interpretation of results

Aggregation

Table 36 shows the aggregated SIA results for each stakeholder group. The aggregation procedure consists of an arithmetic average for all indicators in a stakeholder category. Based on the results, the worst socially impacted group are the workers, with a value of 0.003. Aggregation is not recommended per social impact category because there is too much variability among the categories found in the literature. The only scenario where aggregation at the social impact category level is recommended is if part of the scope of the analysis is to categorize the impacts based on each of the categories. If aggregation is desired per lifecycle stage, the researcher must incorporate this as part of the scope of the assessment. This is important because the list of indicators should be differentiable among the different lifecycle stages. For example, an indicator may read "child labor involvement in any lifecycle stage of the product". This indicator is not appropriate to aggregate per each lifecycle stage. The correct indicator should read in the following manner: "child labor involvement in the production lifecycle stage" or "child labor involvement in the end of life stage". This will then allow aggregation to occur at the different lifecycle stages, but this requires the researcher to consider this from the beginning of the analysis.

Another scenario where the aggregation is useful is when comparing among products or technologies that perform the same function. Let us assume that we perform a SIA of two electricity generating technologies, such as rooftop solar panels and coal-based energy production. When comparing among these two technologies, it is useful to perform aggregation along the stakeholder groups or lifecycle stages. It is recommended that the same list of indicators is used when comparing the two technologies and with the same quantification and normalization procedures. In this scenario it is beneficial to have aggregated values, as it allows for an easier comparison among the two technologies.

In the assessment presented in this chapter, the purpose is informative, meaning that no comparison is performed among different products or technologies. In this case, the use of aggregation is discouraged, unless it is necessary to answer the main questions or objectives of the analysis. Rather, it is recommended to analyze the results of the indicators individually. Comparing aggregated results for the different stakeholder groups as shown may be misleading because the number and type of indicators used for each of the stakeholder group is different, which adds variability to the analysis.

Interpretation of indicator results

The normalized indicator results have been summarized for each stakeholder group and are studied individually below.

Stakeholder Group: Consumers

- Total indicators: 5
- Average positive social impact value: 0.600

Table 37: Normalized results for the consumer stakeholder group.

Indicator #	Indicator Name	Normalized Value
11	Possibility of technology components to be reused for other purposes (circular economy)	1
13	Presence and quality of infrastructure to dispose responsibly of product components	0.5
20	Technology is not expected to increase energy burden	0.75
21	There is evidence that the product is safer than other products used for the same purpose (other energy generating sources)	0.75
22	Do electricity consumers have a choice in the utility company that will be in charge of the technology?	0

Regarding the consumer stakeholder group, the greatest social impacts result from the inability of consumers to choose the utility company in charge of the technology. Other than that and assuming that the quality of housing infrastructure will be able to handle the structural load of the panels, they seem to provide good social performance for the consumers. The ability of solar panel components to be reused for other purposes is of benefit to consumers from a disposal standpoint, as they can dispose of unwanted solar panel components that will be reused. This assumes that there are mechanisms in place to collect such components, which are already in place but can be improved. The panels don't pose any additional dangers to the consumer relative to other energy producing methods.

Stakeholder Group: Local Community

- Total indicators: 9
- Average positive social impact value: 0.556

Table 38: Normalized results for the local community stakeholder group.

Indicator #	Indicator Name	Normalized Value
2	Community trust/approval in technology risk information	1
8	Level of material resource use due to product design decisions	0
9	Number of individuals involuntarily relocating due to technology implementation	0
16	Product design or technology design makes use of local resources and expertise	1
17	Protests to the proposed technology	1
18	Extent to which the technology negatively affects the local community's sense of place and cultural heritage	1
19	Spatial equity of technology: a fair distribution of risks and costs throughout the territory	0.5
23	Is the percentage of the local community expected to be displaced different by population group in the area?	0
24	Is the technology used accessible and affordable to developing countries?	0.5

The solar rooftop technology does not suffer from community resistance of backlash, because it is seen as a green energy producing technology. For the state of Georgia, the technology takes advantage of the local expert personnel and workers in the technology. The greatest social impacts come from its expected impact on gentrification due to increased real estate values. In addition, access to rooftop solar panels is prohibitive to low-income members of the community. Overall, the technology is seen as a positive and environmentally friendly energy generating solution. Its public acceptance along all socioeconomic sectors relies on the implementation of programs for low-income members.

Stakeholder Group: Society

- Total indicators: 6
- Average positive social impact value: 0.617

Table 39: Normalized results for the society stakeholder group.

Indicator #	Indicator Name	Normalized Value
3	Contribution of the technology to economic progress	0.694
4	Energy security	0.550
5	Existence of government regulation on public sustainability reporting for technology	0
7	Income inequalities	0.459
14	Presence and quality of programs to assist in citizens with high energy burdens if technology is implemented	1
15	Presence of public agreement to sustainability using the selected technology	1

The solar industry is booming in Georgia and in the US on the whole. As of 2019, the technology has contributed over $17 billion to the US economy and employs more than 200,000 workers in the US [189]. In the US, there are numerous federal and local programs to assist individuals and businesses in the implementation of rooftop solar technologies.

Stakeholder Group: Workers

- Total number of indicators: 4
- Average positive social impact value: 0.253

Table 40: Normalized results for the workers stakeholder group.

Indicator #	Indicator Name	Normalized Value
1	Child labor involvement in any lifecycle activity	1
6	Health hazard from emissions during any lifecycle activity	0
10	Occupational health and safety (measure by accidents)	0.0111
12	Potential of technology to affect health and safety of workers during the end of life phase	0

The worst social performance is found for the worker stakeholder group. Solar panels involve the use of precious metals that are linked to child labor practices. Because the scope of the assessment is limited to the state of Georgia and the US, this is not considered in the analysis. A significant issue with rooftop solar panels is the risk they pose to workers installing the panels in homes. In addition, recycling and disposing of solar panels presents numerous health hazards to workers if these processes are not properly completed. The recycling and processing of the electronics used in solar panels involve toxic fumes that are detrimental to human health. The success of end of life treatment relies on a proper disposing infrastructure.

8.3 Analysis of SIA application

8.3.1 Recommendations on framework

The learnings from this case study application were implemented in the novel SIA framework by making changes to the process. Although the core of the framework remained similar, important changes were made.

8.3.2 No aggregation is recommended for informative studies

In an informative SIA, the goal is to understand the social impacts of the product or technology being studied. Because there is no comparison among different concepts or products, it's recommended to analyze the indicators individually. Numerous frameworks perform aggregation of the results at multiple levels of the analysis, at the social impact category level, the product lifecycle level and even the stakeholder group level. Aggregation is beneficial when comparing among products that have a similar functionality because it provides an easy and quick way to compare using a single number. In this situation, aggregation is recommended as long as the set of indicators used for the products being compared is the same. In an informative type of study, aggregation may result in a loss of information, as it reduces the impact of multiple indicators into a single number. Although analysts with a technical background may prefer using a number to communicate the social impact performance of a product, it is recommended to provide the numerical performance of each indicator along with a narrative of the result. This should provide a more holistic result than just providing a single number.

8.3.2.1 Use a single set of indicators for comparison or enhancement studies

When comparing among different products or technologies, it is recommended to use the same list of indicators. Having this in mind, the user should have the complete list of products or concepts to be compared, and then populate a list of indicators used in the analysis. The selected indicators should be applicable to all the products being compared. This avoids performing comparison among products using a different set of indicators.

8.3.2.2 Establish aggregation strategy before finalizing list of indicators

Depending on the goal and scope of the analysis, the user may wish to aggregate the social impact results at the product lifecycle level or social impact category levels. It is recommended to establish this during the goal and scope stage. This information is then used in the inventory analysis stage to develop the final list of indicators. Doing so allows the user to express the indicators in a way that matches the aggregation strategy. For example, let us assume that the user aims to compare the social impacts of two products for each product lifecycle stage. To do this, the user must ensure that the indicators are expressed as such; for example, instead of expressing the indicator as "Amount of natural resources used along the product lifecycle", the indicator should read "Amount of natural resources used within the production stage of the product lifecycle". Doing this allows the user to communicate the results as desired.

8.3.3 Limitations

One limitation of the case study application shown in this chapter is that the analysis is performed by a single researcher. In order to reduce bias, it would be beneficial to provide the framework and the case study information to multiple users and perform a comparison study among different users. By studying the results of the different users, differences in the results and in the interpretations of the process can be highlighted and modified. Another limitation of the case study is that only one product is analyzed. A deeper evaluation plan should consider products from multiple industries and functionalities to help detect additional opportunities for improvement in the framework.

8.4 Conclusions

The novel SIA framework has been applied to perform an informative analysis of the social impacts of a rooftop solar panel. It must be clarified that the rooftop solar panel case study analysis shown in this chapter is a low-detail type of analysis that is performed using only secondary data. Having said this, there are steps on the novel SIA framework that are not shown in the rooftop solar panel analysis, such as the benchmarking of indicators using stakeholder input or the collection of primary data. The case study is scoped to the use and end of life phases, and its geography focus is on the state of Georgia in the United States of America. The framework allowed for assessment of potential impacts of the rooftop solar technologies in the state of Georgia. The biggest concerns of the technology implementation result from unwanted displacement due to increased real estate prices, the inequality of access to the technology for low income community members, the dangers it poses to workers installing the solar panels, and the necessity of a proper recycling infrastructure that ensures proper management of solar panel components at the end of their life.

A few recommendations are provided following the case study application will be included in the next version of the novel SIA framework pertains to the comparison of different products or technologies (with similar functionality). During the inventory analysis stage, the user should create a list of indicators that is applicable to all the products being evaluated. This means that the user should know this during the goal and scope stage of the assessment. During this step, the user should define the study as a comparison study, and define the products or technologies being compared. This is necessary because the user will make sure to use a set of indicators that is applicable to all the products being assessed, rather than using different sets of indicators for each of the products being analyzed.

Overall, the objectives of the case study application were achieved. The use of the framework provided social impact information and areas of concern of potential social impacts where efforts should focus if this technology is to be implemented. The case study application highlighted areas of improvement for the framework that will be modified accordingly in the later version of the framework. The case study is the last step of the evaluation plan for the framework. All the learnings from the expert feedback, the capstone student feedback and from the case study application are used to enhance the framework to its final version.

CHAPTER 9 CONTRIBUTIONS

The motivation for the research work presented in this thesis resulted from the recognition of the need for advancement in the social impact assessment field. Relative to the environmental assessment methodologies, SIA methodologies lack consensus and present a high degree of variability that make communication and scientific rigor more difficult. The aim of this research was to contribute to the advancement of the SIA field towards a more robust and reliable methodology. There are five contributions from the research project presented in this thesis.

The first contribution results from the novelty provided by the SIA framework. This is the first framework that uses a set of identified SIA challenges as a starting point. The framework maps the individual challenges identified in the systematic mapping process to each of the assessment stages, and then maps each of these challenges to methods for how to overcome them. Before developing any type of solution, identifying the main challenges is essential, so that an intervention is then developed to overcome those challenges and move the situation from the current to the desired one. This is the goal of the systematic mapping (DS-I) exercise, the identification of the main gaps and issues in the SIA field. It is important to recognize that even though the list of challenges is not exhaustive (it is limited to the articles considered in the systematic review), they do exist, and it is necessary to overcome them to achieve success. This contribution is significant to the SIA field because, even though authors have mentioned the identified challenges in their respective articles, this is the first research that compiles a list of challenges raised by numerous authors in a single document. This list of challenges can be used as a reference for future research to develop solutions that aid in overcoming them. Such research outcomes are imperative to advance the SIA field, but the starting point for such solutions is the identification of the challenges.

The second contribution of this framework, and one of the aspects that makes it novel, applies to S-LCA studies, specifically to the goal and scope assessment stage. The framework proposes the following classification for the analysis type, which is adapted from the work of Kjaer et. al on product service systems [172]: *informative, comparative or enhancement*. Current S-LCA studies don't explicitly make such a distinction; making this distinction is recommended because the type of analysis being performed affects recommendations for the remaining assessment stages. For an informative type of study, the impact assessment results for quantitative indicators should be presented individually without any averaging. For comparative or enhancement studies, it is recommended to use a common indicator database for all products being analyzed. It is only for the comparative or enhancement types of analysis that aggregation is recommended, and aggregation should only be used to compare the SIA results of the different products or concepts being examined.

The third contribution is a summary of academic and non-academic articles, methodologies and case studies in the SIA field. A database of articles has been provided to the reader where the documents are organized based on the following variables: author(s), publication date, title of article, journal name if applicable, case study application, country of author(s), country of application, and industry type. This database is expected to serve as a reference for future SIA practitioners interested in learning from previous SIA applications.

The fourth contribution of this work is the creation of an indicator database. More than 650 indicators (Appendix E) from all the reviewed articles have been organized based on their name, stakeholder group, product lifecycle stage, database name, indicator type, geographic scale, and application. This indicator database is part of the novel SIA framework provided to practitioners, as a reference for their own application. It is recognized that there is a significant amount of indicators used in SIA studies. This has to do with the specificity of the applications being studied, where a general set of indicators would hardly apply to all studies. With this database, the aim is for users to start with the database and then develop their own or look for additional sources if needed.

The fifth and last contribution of this thesis is the novel SIA framework developed. Although it will be developed further, the framework presented in this dissertation provides a methodology to perform a social impact assessment of products and technologies for novice and expert users. Templates to organize the framework and reference information, such as the compilation of previous studies and the indicator database, are provided. There are two aspects that make this framework novel. This is the first SIA framework that uses a set of identified challenges to perform SIA as its starting point. In addition, each of the challenges are mapped to each of the assessment stages, and recommendations on how to overcome the challenges are provided, along with methods and literature to which the user can refer for additional guidance. The goal of this framework is to contribute to the advancement of the SIA field. Such advancement can result from the implementation of the framework in real case studies, or by serving as an inspiration for further improvement of SIA methods. The DRM-based research plan is presented in a transparent manner to promote collaboration in the field.

With this work, we hope to inspire scientists and practitioners to recognize and understand the importance of considering social impacts and their relationship to technical decisions. Advancing the SIA field indirectly involves the advancement of the quality of life of humans and their well-being. Social impacts are present in every technical decision being made during the development of a product of technology. It is therefore important to provide professionals with all the tools needed to incorporate social impact criteria in their decision-making processes. This is essential to adopt a pro-active rather than reactive approach towards social impacts. The main inspiration for this work was to enhance the human quality of life through technical decisions. It is thus recommended that tools, such as the one presented in this document, are incorporated in engineering and design courses at the same level of importance as any other assessment tool. This fact motivated the delivery of two senior capstone lectures to undergraduate students in the school of mechanical engineering in the topic of SIA. In these lectures, students were introduced to the topic of SIA and were provided reference documents and instructions on how to include such a process in their final capstone design and report. The goal was to develop in future engineers and scientists a recognition of the potential social impacts that their decisions as professionals will have on their immediate and extended human population.

CHAPTER 10 FUTURE RESEARCH

The work presented in this thesis document has inspired ideas for future research directions. These research directions are expected to advance the novel SIA framework presented in this thesis and are also expected to advance the social assessment and engineering design fields.

The first future endeavor involves the development of a longer and more complete evaluation plan for the framework. SIAs are applied in a breadth of industries, from product and technology design to policy evaluation. In order for the novel SIA framework to provide the best guidance in most SIA industries, additional case studies should be performed with representation from multiple industries. In addition, it would be of benefit to provide the framework to industry experts where the framework is applied in a professional setting. In this evaluation, the researcher could gather information about the implementation of the SIA framework in the development process of a product, using this information to identify any limitations or needs that the framework is not fulfilling.

The second research direction recommended is to further develop the framework so that it can be applied in the complete development process of a product. The goal of this research would be to incorporate portions of the SIA framework in the engineering design process and describe how it could be applied at the different design stages. For example, during the task clarification stage, the SIA framework should aim to elucidate any customer needs related to social impacts. This information could then be used, along with the functional requirements of the product, to develop design specifications from a social standpoint. This means that in addition to technical and functional feasibility, the product would then have a social feasibility that it needs to satisfy. By incorporating this approach at early design stages, designers are required to consider social criteria from the beginning of the process. This results in a proactive approach to minimize the negative social impacts of a product, rather than relying on reactive measures. To further inform the design process, the social impact criteria could be considered in the conceptual design phase. The social criteria could be incorporated into conceptual development and evaluation tools, such as morphological charts and concept evaluation matrices. The aim would be to incorporate social impact criteria at the earliest design stages, where there is the greatest potential to inform and affect the final design decisions.

The third research direction recommends collaboration and research with experts from the social sciences. Due to the technical background of lifecycle assessments, many social impact practitioners prefer the use of quantitative assessments over qualitative assessments. Although there is nothing wrong with quantitative assessments, it is important that practitioners are aware of the dangers of quantification of social criteria. When using numbers to study social criteria, one must be careful and sensible to not represent a detrimental social aspect with a “number”. Although numbers are beneficial for communication and design specification purposes, qualitative methods and analyses provide a significant amount of learning about social issues, learnings that might not be able to be captured by numbers. To provide a more holistic approach, collaboration efforts between technical and social sciences should aim to educate practitioners on the dangers of over quantification and on the development of novel methods that will help more technical practitioners avoid losing customer need information due to the use of purely quantitative approaches.

The fourth research direction recommends interdisciplinary collaboration with engineering education experts. The goal of this research would be to develop curricula that includes social impact assessment and methods into existing engineering design courses. These research endeavors would be in line with the 2019-2020 student outcome goals of the Accreditation Board of Engineering of Technology (ABET) [190]:

- "Student Outcome #2 requires an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors."
- "Student Outcome #4 requires ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts."

The effort could teach students methods to incorporate social criteria in their design processes and to perform social impact assessments of existing and prospective product and technologies.

Overall, future research should focus on the development of better social impact assessment methods and on educating future professionals in how to use them. Social criteria should be considered to be as important as economic and environmental criteria. Social impacts are tied to technical decisions, and it is essential for future professionals to have access to tools and methods to better understand such relationships. Scientists, engineers and professionals should understand that their role is to make decisions that enhance the human quality of life, regardless of the technical and economic challenges this may present.

CHAPTER 11 LIMITATIONS

In this chapter, the limitations of this dissertation are discussed, as organized by the DRM framework stages, DS-I, PS, and DS-II. Overall, there is a limitation of this framework that is present for all decision support frameworks: the nature of expertise itself. Some of the values discussed in SIA involve topics on equity and autonomy, values that are better understood by the individuals being affected than by the "experts" using the framework. In this respect, it is recognized that this framework is used by experts based on their best understanding of what is considered best for all stakeholders involved, but that the real experts are the stakeholders themselves.

DS-I stage limitations

The first limitation of this research occurs during the DS-I stage, specifically with the systematic mapping activity presented in Chapter 4 of the thesis. Although the review aimed to be as inclusive as possible, there are inherent limitations to the amount of articles and reports that can be included. Articles that were not written in the English language were not included, nor were articles that were not available online, so it is advised that the learnings from the systematic mapping exercise are limited to the articles being included. This means that although there were twelve challenges identified, this list is not exhaustive, as there may be additional challenges that are present that were not mentioned in the articles included in the systematic mapping.

PS stage limitations

The PS stage involves the development process of the novel SIA framework, and there are a few limitations identified for this stage. The framework may be based on a potential incomplete list of challenges. The purpose of the framework is to provide user guidance in overcoming the set of challenges identified in the DS-I stage during the systematic mapping process; if such a list is not complete, there might be additional challenges for which guidance is not provided. It must be noted that the initial version of the framework was developed based on twelve identified challenges, instead of the revise set of ten challenges after incorporating the expert feedback results. Even though ways to address each of the challenges is provided, this list is not all inclusive. There might be additional methods not provided in the framework to address each of the challenges that were not captured in the literature review. In addition, the PS stage generated the simplified framework provided to the capstone students for the novice user feedback. Because this framework version did not include a data collection or impact assessment calculation, learning within these areas will be limited for those who implement it. Finally, the framework is static, meaning that the analysis is performed at one point in time, rather than allowing for continuous input and analysis to aid in the socially responsible design decision-making process. For the future, a framework that could be used more frequently and briefly throughout the design process would allow for incorporating of new information to continually inform design actions.

DS-II stage limitations

The second set of limitations is regarding the evaluation plan presented in the DS-II stage. The evaluation plan consisted of the following three activities: expert feedback, novice user (capstone student) feedback, and theory testing through a case study application. The expert feedback activity was limited due to its low participation rate. Even though the results from the expert feedback are not intended to establish any statistical significance, it would be of benefit to gather feedback from as many experts as possible. In the future, it is recommended to establish direct contact with the experts before requesting them to complete the survey. This would allow for the researcher to introduce the project to the experts and potentially solicit higher participation and response rates. In addition, it would beneficial to organize a workshop in which experts from different industries are provided the framework. During this workshop, the experts could apply the novel SIA to a set of case studies and the feedback could be collected at the end of the day.

The novice user feedback activity had two limitations. The first limitation is that it was not a controlled study. In order to assess the effectiveness of the SIA framework, ideally two different groups of students would be used, one with access to the framework and another without access to it. The students would then be asked to perform the same social impact assessment, with and without the framework. The results from the two groups could be analyzed to understand how effective the support is provided by the SIA framework. The second limitation is the small sample size of novice users. Although the feedback exercise still provided valuable information about the framework and how it could be enhanced, no modelling or estimations can be made about the populations tested. To remedy these two limitations, future studies should consider the participation of a control group that does not have access to the SIA framework and in addition to the group that has access to the SIA framework. The sample size of novice user study should allow for statistical estimations about the novice user population.

Another limitation of the evaluation plan was in the case study application. The first limitation is in the data quality assessment process was performed by a single researcher.

However, best practice recommends performing the analysis be performed independently among a group of researchers who corroborate agreement among the different quality criteria assessments. This should reduce any subjectivity bias present in the assessment of the data quality. The second limitation relates to the fact that only one product is being evaluated. Although the rooftop solar panel assessment provided important insights about the framework, it would be beneficial to develop a structured case study evaluation plan that considers a variety of products and industries. This is essential, as SIA are applied across a breadth of topics, from products and technologies to policy evaluation; considering case studies from different industries would provide additional insights to the framework. Another limitation of the case study is that it was completed by a single researcher, and this may result in bias in the results.. In future case studies, a group of researchers should apply the SIA framework to the same case study in order to detect and minimize bias. The portions of the analysis with a higher risk of bias occur at the inventory analysis assessment stage, more specifically during the selection of relevant indicators and the performance reference points (PRPs), and during the impact assessment stage, where scores are given to semi-quantitative indicators.

CHAPTER 12 CONCLUSIONS

A novel SIA framework is presented in this dissertation. Using DRM as the backbone of the research plan, the work presented was divided in three steps. The first step involved a systematic review of the SIA field. This process resulted a detailed understanding of the SIA field by means of a systematic mapping of academic and non-academic literature. One of the main findings of the systematic mapping was the identification of twelve recurring challenges to perform SIA. The challenges are now organized in a single document, serving as a reference for future SIA researchers. An additional finding of the mapping is the historical publication trends of SIA articles in the recent decade, which shows an increased interest from researchers in social assessments. SIA articles also revealed that most SIAs are performed post-implementation of the product or technology being studied. This finding reveals one of the key challenges of SIA, which is that of having access to the needed information in a pre-implementation state. When a product or technology is already implemented, researchers can rely on historical or current data to perform their assessments because the product supply chain and lifecycle is already studied. The level of detail of the analysis depends more on the definition of the study boundaries and the available resources. During pre-implementation, there are many aspects about the product lifecycle and supply-chain that are still unknown. This means that regardless of the available resources to perform the study, a pre-implementation study will present higher data-availability challenges relative to a post-implementation study. This itself leads into another important finding of the systematic mapping, which is that a very small number of the case studies were performed at early design stages of the product or technology being assessed. There is a need to develop frameworks that are implemented during the early stages of the design process. This is why it is recommended that frameworks are developed that allow for the incorporation of social criteria during the early design stages of a product. Another significant finding of the systematic mapping is that the majority of SIA studies used methodologies that are based on the ISO 14040 LCA structure [3]. Although the LCA structure has proven to be useful, it would be interesting for researchers to innovate and develop non-LCA based structures and see how they compare.

The set of challenges were used as inspiration for the second step of this dissertation research, which was the development of a novel SIA framework. Based on the finding from the systematic mapping that 88% of SIA studies apply LCA type frameworks, it was decided that the novel SIA framework developed in this thesis would also adopt an LCA structure. This structure also allows integration of the SIA framework with other LCA methods, such as Life Cycle Costing (LCC) and Environmental Life Cycle Assessment (E-LCA), which assess the impacts of the product lifecycle with respect to the economic and environmental dimensions. The current S-LCA field is experiencing a surge in interest, which is reflected in the increased number of academic and non-academic articles being published and in the increased adoption of social assessment methods by industry and governments. Although S-LCA has proven useful for decision-making purposes and for gaining a better understanding of potential social impacts of a product's lifecycle, the methodology still needs further research before a standardized method can be achieved. S-LCA is known to have methodological weaknesses related to the selection of indicators, the definition of the system boundaries, the selection of reference values used in the characterization process, and the selection of weighting values.

The novel SIA framework presented is also an S-LCA, as its structure consists on the following four stages: *goal and scope, inventory analysis, impact assessment* and *results interpretation*. The impact assessment methodology is based on performance reference points (PRP), which makes it a Type I S-LCA methodology. The assessment is based on the use of impact indicators that are associated to stakeholder groups, so it is a stakeholder-theory based methodology.

Relative to the current methodologies, the novel SIA framework either improves upon, expands or follows a different approach relative to what is currently being done in the S-LCA field. Regarding the goal and scope assessment stage, the novel framework provides an improvement based on the definition of the level of detail of the study. Different levels of detail will require different data quality assessment requirements and different data source requirements. For low-detail studies, only secondary data-sources may be used. For high detailed studies, primary data is required. Also, data quality requirements are more stringent for highly detailed studies. The overall strategy recommended in this framework is to use a two-step approach for the analysis. The first step is to perform a low-detail study that incorporates as much information as possible within its boundaries. The results from such an analysis are then used to perform a more-focused, higher detail analysis that relies on primary data. Regarding the inventory analysis, an improvement is made by forcing the user to define the aggregation procedure before creating the indicator database. This is needed so that the indicators are defined in a way that it allows for the desired level of aggregation. For example, indicators to be aggregated at the stakeholder group must be defined per stakeholder group or per product lifecycle stage; otherwise, the desired aggregation is not possible. For the interpretation of results stage, the results for the indicators must be a combined numerical and qualitative assessment to reduce misinterpretation. The qualitative assessment should be in the form of a narrative, and should complement the numerical indicator value.

The novel framework expands the inventory analysis stage of current methods. As part of the systematic mapping, a database of previous studies is provided. These studies are classified according to important criteria and are expected to prevent scientists from embarking on studies that have already been performed, or to use them as a source of inspiration for their own studies. A database of indicators is provided, which is populated with the articles used in the systematic mapping procedure. The goal of this database is to get the field closer to developing an established database of indicators.

How is the SIA framework novel or different from current S-LCA methodologies? There are two aspects that make this framework novel. The first aspect is that this is the first SIA framework that uses a set of identified challenges to perform SIA as its starting point. The framework provides a direct mapping between the framework assessment stage, the related challenges, and the corresponding methodologies to overcome each of the challenges. The aim is to contribute to the development of a standard SIA methodology by providing a framework with a holistic approach, rather than providing a framework that addresses only a subsection of the challenges. The recommendations available to overcome each of the challenges combine current methodologies available in the literature, along with databases of indicators and of current social assessment studies. The second aspect relates to the goal and scope assessment stages of the analysis. An analysis classification scheme adapted from the work of Kjaer et al. [172], classifies the analysis into one of the following three types: *informative, comparative* or *enhancement.* Current S-LCA methods don't explicitly make such a distinction; however, it is recommended to make this distinction because the type of analysis being performed is linked to recommendations in the inventory analysis and impact assessment chapters. When doing an informative type of study, the impact assessment results for quantitative indicators should be presented individually, without any averaging. For comparative or enhancement studies, it is recommended to use the same indicator database for all products being analyzed. It is only in these two types of analyses that aggregation is recommended, and it should only be used to simplify the comparison process rather than to interpret individual results.

The main finding of the framework development step is the iterative nature of the framework development process. Although the process is presented as sequential, the process iterated between user feedback, case study feedback and framework changes. In order to continue developing the novel SIA framework, it is advised to continue performing cycles of the following steps: user feedback, theory testing through case studies, and identification of improvement opportunities. This process is presented by Kjaer et.al [118] in their development of guidelines to evaluate the environmental performance of product service systems (PSS).

The final component of the research plan is the evaluation of the novel SIA framework. This consisted of a combination of feedback and a case study application. Feedback was collected electronically from experts and novice users (senior capstone students) and was used to enhance the framework. The novice study feedback highlighted areas in which the simplified SIA framework should be enhanced. One learning is that the students struggled the most with design recommendations to reduce social impacts in future design iterations. Although guiding questions and an example were provided in the SIA template, additional lecture time and a more detailed example might help students with this task. Another learning from the novice feedback is that all users performed the SIA on the final design iteration of their project. Perhaps it would be beneficial to provide students with additional methods to perform SIA at earlier design stages, such as during the conceptual design stage. Overall, the novice user feedback was positive, and most students did a great job in the SIA of their capstone designs.

The feedback activities verified how valuable having user feedback is in the development process of a framework. User feedback revealed important limitations of the framework that may have otherwise go unnoticed by the developer. The expert feedback resulted in the elimination of challenges #10 and #11. Challenge #10, "selection of global or location specific data" was removed because it was considered a decision about the study design, rather than a challenge to performing SIA. Rather than being a limitation to performing the SIA, the decision to use either type of data depends on goal and scope of the analysis. Challenge #11, "selection of scoring scales for reporting the results", was also removed because it is considered more a part of the interpretation and communication of the results, rather than a challenge to performing SIA. Aside from the removal of the two challenges, the expert feedback was positive, as it validated the remaining ten challenges identified from the systematic mapping. Although having novice user feedback is valuable to identify any shortcomings of the guidance provided by the framework with inexperienced users, expert feedback has higher credibility and aims to improve the usability of the SIA framework in professional practice by identifying conceptual problems that require a higher level of experience and knowledge. Experts understand from experience the full context of SIA and LCA, so their feedback is better reflective of the

SIA framework user needs with regards to the challenges to performing SIA than novice users that have never perform an SIA.

The case study application consisted of applying the novel SIA framework to understand the potential social impacts of rooftop solar panels in the state of Georgia. The analysis focused on the use and end of life stages of the solar panels and provided insights into enhancing the novel framework. The main finding of the case study application is the importance of the data collection step in the analysis. Even if the methodology used to perform the SIA is flawless, the learnings from the analysis will be limited if improper data is used. SIA always rely on the use of primary or secondary data to perform the analysis. It is therefore recommended that future SIA studies allocate the necessary time and financial resources to data collection efforts. It is also recommended that future SIA research focuses on developing methods that are accessible to SIA researchers, ideally free of cost, that comply with the strictest data quality requirements. Such accessibility will be of benefit to all SIA practitioners, even more to those that have financial limitations to pay access to reliable online databases.

The application of the research plan resulted in key findings and in the answering of the two research questions of this work:

RQ1) What are the recurring challenges and limitations faced by the current methods and frameworks available to perform social impact assessment of products?

RQ2) How can the user be guided through the social impact assessment process to succeed among these challenges?

The work presented in this dissertation has scientific and social relevance. The scientific relevance of this work is the provision of a novel SIA framework, along with a set of challenges to performing SIA. These challenges can be referenced by researchers as an impetus to develop their own solutions to overcome such challenges. The development of the novel framework provides the user guidance to perform SIA and a database of existing methods and indicators that can be used as a starting point for SIA.

From a social standpoint, the work presented in this document highlights the importance of considering social impacts in the design process of products and technologies. Technical decisions are inherently social decisions, and it is important for designers to acknowledge the long-lasting effects of their decisions. Part of this acknowledgement means having access to methods that allow for a better understanding of the social impacts implied in their decision-making processes. By having a better understanding, it is expected that designers and scientists will be able make technical decisions that improve the human quality of life. The hope is that going forward, designers would incorporate social criteria in the design and development process of products. These social criteria are expected to be included at early design stages, where there is a higher potential to affect the final product. This should create a proactive rather than reactive approach to social impacts and should result in the development of products that have a more positive social impact.

Although it is believed that having access to better SIA methods is essential to improving the social impacts of future products, one has to consider what the motivation is for industries to consider social criteria in their product development process. Industries are already facing significant challenges in the development of products due to increased regulatory and social pressure to produce environmentally friendly products. Including social criteria will add complexity and cost to the development process. This is where we recognize one of the limitations of the work presented in this document, but one that is outside the scope of this work and that deserves much attention. The provision of novel frameworks and methods to perform SIA should be accompanied by regulation and policy that requires companies to incorporate such aspects in their design process. It is recognized that this will make more difficult the already complex and costly product development process; however, the same was said about considering environmental impacts, which has resulted in the development of new markets for “greener” products. Readers and future researchers are thus encouraged to investigate appropriate methods to help companies adopt safe strategies to enable them to incorporate social criteria in their products without threatening their economic well-being.

It is also of interest to motivate future researchers to integrate engineering design and engineering education research with the social sciences. Studying social impacts is challenging due to the subjectivity of the criteria being studied. SIA should incorporate more qualitative approaches that allow a proper understanding of social impacts. Rather than wanting to only rely on quantitative analysis, both quantitative and qualitative analyses should be combined to provide a more holistic assessment. As with SIA methodologies in general, it would be of social benefit to incorporate the study of social impacts in undergraduate engineering curricula. The goal would be to equip the engineers of the future with the tools necessary to assess and understand the potential social repercussions of their design. For students, the hope would be that this instruction would raise social impacts to the same level of importance as environmental and economic impacts during the development process of products.

Engineers and scientists have a moral responsibility to develop products that enhance the quality of life of all human beings, regardless of their socio-economic or demographic characteristics. It is the duty of educators and professionals to raise awareness of the potential social impacts of products. After all, regardless of whether the social impacts of our technical decisions are distant or near, they end up affecting the human race as a whole.

APPENDIX A SYSTEMATIC LITERATURE REVIEW PROTOCOL TEMPLATE

Systematic Literature Review Protocol template

Question Formulation

Question Focus:

Question Quality and Amplitude:

Problem:

Question:

Keywords and synonyms:

Intervention:

Control:

Effect:

Outcome Measure:

Population:

Application:

Experimental design:

Sources selection

Sources selection criteria definition:

Studies languages:

Sources identification

Sources search methods:

Search string:

Sources list:

Sources selection after evaluation:

Studies Selection

Studies definition

Studies inclusion and exclusion criteria definition:

Studies types definition:

Procedures for studies selection:

Information Extraction

Information Inclusion and Exclusion Criteria Definition:

Results Summarization

Results presentation:

APPENDIX B EXPERT FEEDBACK SURVEY

Challenges in Social Impact Assessment

Welcome to the Challenges in Social Impact Assessment Expert Review Survey!

Thank you for considering participating in this electronic survey. We are currently conducting research on the topic of social impact assessments, specifically on its challenges. By means of a literature review, a set of recurring challenges for performing social impact assessments have been identified. The goal of this survey is to gather expert feedback regarding the identified challenges with regard to their correctness, importance, and completeness. The survey should take between 15-30 minutes to complete, and your answers will be anonymized before analysis or publication. If there any questions regarding the survey, please feel free to contact Ricardo J. Bonilla-Alicea at the following email: rjba3@gatech.edu.

When you are ready, please click the next button to start the survey.

WAIVER OF DOCUMENTATION OF CONSENT FOR ENROLLING IN A RESEARCH STUDY

Georgia Institute of Technology

Project Title: Identifying Challenges for Social Impact Assessment through Systematic Literature Review

Investigators:

Katherine Fu, PhD., Assistant Professor, Georgia Institute of Technology

Ricardo J. Bonilla-Alicea, Graduate Student, Georgia Institute of Technology

You are being asked to take part in a research study.

<u>Purpose:</u>

The purpose of this study is to understand the set of challenges that practitioners face when performing a social impact assessment. A set of challenges have been identified by means of a systematic literature review. Now, expert feedback is requested to revise and provide additional feedback to the list of challenges identified.

Exclusion/Inclusion Criteria:

For this study, you should: Be over 18 years old Have completed work regarding environmental impact assessments, economic impact assessments, social assessments or participation in work groups and/or research related to social assessments in general. Be a fluent English speaker. Be able to consent to participate.

For this study, you should not: Have difficulty reading, writing or understanding English language. Be under 18 years old. Be unable to meet the inclusion criteria in the list above

Procedures:

If you decide to be in this study, your part will involve data collection lasting 30-45 minutes, including: Demographic survey questions Open-ended and Likert scale survey questions about challenges to social impact assessment Remember, you may stop if you want to quit, and you may withdraw at any time.

Risks or Discomforts:

The risks involved are no greater than those involved in daily activities as a professional.

Benefits:

You are not likely to benefit directly in any way from participating in this research. Indirect benefits may include feelings of satisfaction for contributing to the improvement of the field of social assessments, and exposure to a summarized and condensed set of challenges when performing social impact assessments, which may (or may not) help you in your professional career.

Compensation to You:

You will not be compensated for your participation in this study.

Confidentiality:

The following procedures will be followed to keep your personal information confidential in this study: The data collected about you will be kept private to the extent required by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear if results of this research are presented or published. Once the study is complete, all records identifying you will be disposed of and deleted from all digital files. Your privacy will be protected to the extent required by law. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records. The Office of Human Research Protections may also look over study records during required reviews.

Costs to You:

There are no costs to you, other than your time, for being in this study.

In Case of Injury/Harm:

If you are injured as a result of being in this study, please contact Katherine Fu, Ph.D., at telephone (404) 385-3810. Neither the Principal Investigator nor Georgia Institute of Technology has made provision for payment of costs associated with any injury resulting from participation in this study.

Participant Rights:

Your participation in this study is voluntary. You do not have to participate in this study if you don't want to be. If you decide not to participate, you will not be enrolled. You have the right to change your mind and remove yourself from the study at any time without giving any reason and without penalty. Any new information that may make you change your mind about participation in this study will be given to you. You will be given a copy of this consent form to keep. You do not waive any of your legal rights by signing this consent form. Your participation and/or performance will have no impact on your academic standing or status at Georgia Institute of Technology.

Questions about the Study:

If you have any questions about the study, you may contact Dr. Katherine Fu, Investigator at telephone (404) 385-3810 or katherine.fu@me.gatech.edu

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact

Ms. Melanie Clark, Georgia Institute of Technology

Office of Research *Integrity Assurance*, at (404) 894-6942.

[or]

Ms. Kelly Winn, Georgia Institute of Technology

Office of Research *Integrity Assurance*, at (404) 385- 2175.

By clicking "next" and proceeding to the survey, you are indicating that you have read and understand the above informed consent information and are choosing to voluntarily participate in this study. If you do not consent, please exit the survey now.

Are you located in a country that is part of the European Union?

- ○ Yes
- ○ No

INSTITUTIONAL REVIEW BOARD (IRB)

CONSENT FOR THE COLLECTION AND PROCESSING OF SPECIAL CATEGORIES OF SENSITIVE PERSONAL DATA FROM THE EUROPEAN UNION   1) Pursuant to the European Union General Data Protection Regulation (EU GDPR), the Georgia Institute of Technology ("Georgia Tech"), in its capacity as a data controller under the EU GDPR, must obtain your explicit, affirmative consent before it can collect or process any special categories of sensitive personal data for a lawful basis, including, but not limited to, employment, admission and enrollment, study abroad, internship abroad, online education, research, etc. For information on how Georgia Tech uses data, please review Georgia Tech's Privacy notice at: http://www.gatech.edu/privacy For information on how Georgia Tech's IRB uses data, please review Georgia Tech's IRB Privacy notice at: http://researchintegrity.gatech.edu/forms/IRB/EU_GDPR_IRB_Privacy_%20Notice_%2008_17_2018.pdf   2) Special categories of sensitive personal data includes racial or ethnic origin; political opinions; religious or philosophical beliefs; trade union membership; genetic, biometric data; health data; or data concerning a person's sex life or sexual orientation.   3) Any special categories of sensitive personal data that is collected from you will be for the sole purpose of participation in a research study [protocol number] with title “Identifying Challenges for Social Impact Assessment through Systematic Literature Review” and is necessary for that purpose. This may include processing the special categories of sensitive personal data as required to execute contractual obligations in connection with the previously described purpose and compliance with applicable laws, to execute the obligations to you concerning your participation in a research study [protocol number] with title “Identifying Challenges for Social Impact Assessment through Systematic Literature Review”. 4) Special categories of sensitive personal data will be handled and processed only by the persons who are responsible for the necessary activities for the purpose above and will be transmitted from the EU to the Georgia Tech Atlanta campus. Georgia Tech is a unit of the Board of Regents of the University System of Georgia (the “BOR”), and data is shared with the BOR and its employees. 5) Refusal of consent may make it impossible for Georgia Tech to carry out its necessary activities for the purpose above, and may preclude Georgia Tech’s ability to provide requested participation in a research study. 6) You have the right to withdraw your consent to the collection and processing of special categories of sensitive personal data. If you would like to withdraw consent, please contact irb@gatech.edu. 7) Georgia Tech is committed to ensuring the security of your information. We have put in place reasonable physical, technical, and administrative safeguards designed to prevent unauthorized access to your information. 8) Georgia Tech has an EU GDPR Compliance Policy which includes your individual rights concerning your data. Please see the EU GDPR Compliance Policy here on the Georgia Tech Policy Library: http://www.policylibrary.gatech.edu/legal/eu-general-data-protection-regulation-compliance-policy

Having read this notice, I hereby

○ give consent

○ do not give consent

for the use of special categories of sensitive personal data, and the transfer of special categories of sensitive personal data overseas, for the purpose outlined in this notice.

Please select today's date

Month	▼ January ...
Day	▼ January ...
Year	▼ January ...

Please sign your name here:

I also hereby waive my right to privacy of confidentiality regarding (please enter EU Institution hosting student/employee) reporting to the appropriate authorities at Georgia Tech if I am seriously ill, suffer an injury, am the victim or perpetrator of harassment, whether on or off campus, am the victim of the perpetrator of sexual or gender-based misconduct and/or of criminal behavior, whether on or off campus, and I grant the authorities of (please enter EU Institution hosting student/employee) staff, faculty and administrators full authority to report to the appropriate Georgia Tech authorities any and all such incidents, under the applicable laws (including but not limited to Title IX and the Clery Act), whether or not it involves disciplinary action.

Month	▼ January ...
Day	▼ January ...
Year	▼ January ...

Printed Name

Please sign your name here:

What is your age?

- ◯ 18-25 years old
- ◯ 26-30 years old
- ◯ 31-35 years old
- ◯ 36-40 years old
- ◯ 41-50 years old
- ◯ 51-60 years old
- ◯ 61-70 years old
- ◯ 71-80 years old
- ◯ 81+ years old

What is your gender?

- ☐ Man
- ☐ Woman
- ☐ Other - Please specify ______________________________
- ☐ Prefer not to say

How would you classify yourself?

- ☐ Arab
- ☐ Asian/Pacific Islander
- ☐ Black
- ☐ Caucasian/White
- ☐ Hispanic
- ☐ Indigenous or Aboriginal
- ☐ Latino/a/x
- ☐ Multiracial
- ☐ Prefer not to say

☐ Other - Please specify:

____

What is your first language?

____

Other languages spoken

____

Please describe any roles or jobs you've held related to performing environmental, economic or social assessments, including dates/duration:

____

____

In what country are you located?

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The next series of questions will focus on the set of identified challenges faced by practitioners completing social impact assessments. A total of 12 challenges have been identified by means of a literature review protocol. For each of the challenges, a set of multiple choice and open-ended questions are provided along with a corresponding explanation of the challenge. The information provided by the participants completing the survey will be used to verify each of the challenges with respect to correctness and completeness. Please click the next button to start the challenges section of this survey.

Challenge #1: Determination of what social impacts to consider and how to quantify them Part of the issue with the determination of social impacts is that there are varying definitions of what should be considered a social impact. As pointed out in Grijalva et al. [1], “The categorizations of social performance measures presented in the literature vary greatly, resulting in non-uniform assessments in practice." Another issue with social impacts is the fact that their evaluation may be seen as subjective by the different stakeholders, which is further exacerbated by the lack of a standard code of practice when performing social impact assessments [2].

References:

[1] P. Grijalva, L. Darrow, and W. Mirdad (2016) “Balance scorecard approach in assessing social impact performance measures”

[2] G. Arcese, M. C. Lucchetti, I. Massa, and C. Valente (2018) “State of the art in S-LCA: integrating literature review and automatic text analysis”

Do you think that this articulated challenge to performing social impact assessments exists?

- ○ Yes
- ○ Maybe
- ○ No
- ○ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- ◯ Extremely important
- ◯ Moderately important
- ◯ Slightly important
- ◯ Not important at all
- ◯ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #2: Uncertainty with indicator selection, normalization, weighting, and aggregation Regarding the selection of indicators, practitioners have the option of selecting them from a predetermined database, or in some cases they develop their own indicator set. As stated by Zanchi et al. [3], "a robust approach for indicators selection is seldom discussed and reported in a transparent way." The normalization step aims at allowing for the comparison of results with very different numerical scales. Siebert et al. [4] raises the fact that there is no standard characterization method yet in social impact assessment. Because there are numerous approaches used in literature to determine weighting values and to perform the aggregation of results, it is difficult to perform comparisons among studies that use different methods.

References:

[3] L. Zanchi, M. Delogu, A. Zamagni, and M. Pierini (2018) "Analysis of the main elements affecting social LCA applications: challenges for the automotive sector"

[4] A. Siebert, S. O'Keeffe, A. Bezama, W. Zeug, and D. Thrän (2018)"How not to compare apples and oranges: Generate context-specific performance reference points for a social life cycle assessment model"

Do you think that this articulated challenge to performing social impact assessments exists?

- Yes
- Maybe
- No
- I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- Always
- Sometimes
- Rarely
- Never
- I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- Extremely important
- Moderately important
- Slightly important
- Not important at all
- I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #3: Determination of whether a functional unit should be used

The functional unit is defined as a measure of the performance outputs of the product systems [5]. Social impact assessments deal with a higher level of qualitative indicators that are not tied to a functional unit. The use of a functional unit is affected by numerous factors such as the scope of the analysis, the relevance of the process, the product system scheme and even the system boundary definition [6]. Some studies considering qualitative data emphasize that it is not possible to express the impacts using a functional unit.

References:

[5] R. K. Singh, H. R. Murty, S. K. Gupta, and A. K. Dikshit (2012) "An overview of sustainability assessment methodologies"

[6] P. Rafiaani, T. Kuppens, M. Van Dael, H. Azadi, P. Lebailly, and S. Van Passel (2017) "Social sustainability assessments in the biobased economy: Towards a systemic approach"

Do you think that this articulated challenge to performing social impact assessments exists?

- ○ Yes
- ○ Maybe
- ○ No
- ○ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

◯ Always

◯ Sometimes

◯ Rarely

◯ Never

◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

◯ Extremely important

◯ Moderately important

◯ Slightly important

◯ Not important at all

◯ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #4: Determination of minimum criteria to be satisfied during data collection efforts

Data collection is often regarded as the most difficult and time intensive part of a social impact assessment [7]. Regardless of the data source selected for the analysis, high quality data is imperative to prevent errors committed at the data collection stage to be propagated along the rest of the analysis. Before embarking in the data collection process, practitioners should have a predefined data quality criterion that must be satisfied by the collected data before using it in the analysis. Although practitioners are using criteria to assess the quality of the data, having a universal minimum criterion would aid in preventing the use of data that is prone to cause errors later on in the analysis. References: [7] A. Brown (2016) "Social Life Cycle Metrics for Chemical Products - A guideline by the chemical sector to assess and report on the social impact of chemical products, based on a life cycle approach"

Do you think that this articulated challenge to performing social impact assessments exists?

- ◯ Yes
- ◯ Maybe
- ◯ No
- ◯ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- ◯ Extremely important
- ◯ Moderately important
- ◯ Slightly important
- ◯ Not important at all
- ◯ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #5: Allocation of social impacts into different categories

The use of indicators when performing a social impact assessment involves their classification into different groupings called impact categories. There is currently no standard method for performing this classification procedure, which may be subject to bias or subjectivity. This lack of rigor may affect the validity of the results and make the comparison among studies that use different allocation methods more difficult.

Do you think that this articulated challenge to performing social impact assessments exists?

- ◯ Yes
- ◯ Maybe
- ◯ No
- ◯ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- ○ Extremely important
- ○ Moderately important
- ○ Slightly important
- ○ Not important at all
- ○ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #6: Connection of social impacts with products rather than with the conduct of companies producing the products

A practitioner performing a social assessment of a product may want to focus on the companies involved with producing such a product. In this case, the social impacts of the product would be determined by the conduct of the companies producing the product rather than on the product itself [8]. This presents a significant challenge when a group of designers is evaluating different design alternatives of a product, and the process of selecting the more socially sustainable alternative becomes a matter of the conduct of companies rather than of technical specifications of the product itself.

References:

[8] A. Siebert, A. Bezama, S. O'Keeffe, and D. Thrän (2018) "Social life cycle assessment: in pursuit of a framework for assessing wood-based products from bioeconomy regions in Germany"

Do you think that this articulated challenge to performing social impact assessments exists?

- ○ Yes
- ○ Maybe
- ○ No
- ○ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- ◯ Extremely important
- ◯ Moderately important
- ◯ Slightly important
- ◯ Not important at all
- ◯ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #7: Definition of "social well-being" used in the analysis

The World Health Organization (WHO) recognizes that there is no universal definition of social well-being, as it may have different connotations for different individuals [9]. The definition of social well-being used in the social impact assessment is important, since the goal of performing social assessment is to minimize any detrimental impacts on stakeholders. The definition becomes especially important when using frameworks that have social well-being as part of their analysis.

References:

[9] World Health Organization (2019), "Promotion of mental well-being"

Do you think that this articulated challenge to performing social impact assessments exists?

- ○ Yes
- ○ Maybe
- ○ No
- ○ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- ◯ Extremely important
- ◯ Moderately important
- ◯ Slightly important
- ◯ Not important at all
- ◯ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #8: Selection of a preferred method to perform the social impact assessments

While there are many social impact assessment approaches available in the literature, there is a lack of a standard method to be agreed upon [8,10]. When performing environmental impact analysis, ISO 14044 provides a general framework for performing the analysis. Although ISO 14044 has been criticized for not been detailed enough, it still provides a general methodology to follow. Such a standard is not available for performing social impact assessments. Having an agreement on a standard method to perform the social impact assessment will reduce the variability of the methods used and will simplify the comparison of results across studies.

References:

[8] A. Siebert, A. Bezama, S. O'Keeffe, and D. Thrän (2018) "Social life cycle assessment: in pursuit of a framework for assessing wood-based products from bioeconomy regions in Germany"

[10] N. Iofrida, A. Strano, G. Gulisano, and A. I. De Luca (2018) "Why social life cycle assessment is struggling in development?"

Do you think that this articulated challenge to performing social impact assessments exists?

- ◯ Yes
- ◯ Maybe
- ◯ No
- ◯ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- ◯ Extremely important
- ◯ Moderately important
- ◯ Slightly important
- ◯ Not important at all
- ◯ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

Challenge #9: Definition of the system boundaries

System boundaries define which inputs and processes are included in the social impact assessment. They also determine the data that needs to be gathered to perform the assessment. The lack of a standardized method to define the boundaries of the analysis complicates the process of comparing results from different social impact assessments.

Do you think that this articulated challenge to performing social impact assessments exists?

- ◯ Yes
- ◯ Maybe
- ◯ No
- ◯ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- ○ Extremely important
- ○ Moderately important
- ○ Slightly important
- ○ Not important at all
- ○ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #10: Selection of global or location specific data

Some social impact assessments are performed only for screening purposes, using country or sector level data to detect areas of crucial improvement [12], a process known as social hotspot analysis. When performing a more detailed analysis, the use of site-specific data is recommended. The selection of global or specific data affects the level of learning that could be obtained from the analysis, which is why it is a decision that must be well documented and well considered.

References:

[12] C. B. Norris, D. Aulisio, and G. A. Norris (2012) "Working with the Social Hotspots Database - Methodology and Findings from 7 Social Scoping Assessments"

Do you think that this articulated challenge to performing social impact assessments exists?

- ○ Yes
- ○ Maybe
- ○ No
- ○ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

○ Always

○ Sometimes

○ Rarely

○ Never

○ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

○ Extremely important

○ Moderately important

○ Slightly important

○ Not important at all

○ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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Challenge #11: Selection of scoring scales for reporting the results

There is currently no general standard for interpreting the results of social impact assessments. The variety of numerical scales used to report the results from social impact assessments are proof of the lack of a standard. As shown by Singh et al. [12] “While Hosseinijou et al. [13] have taken a 6-point scale with values ranging from 0 to 9, Foolmaun and Ramjeeawon [14] have gone for a 5-point scale with values ranging from 0 to 4." The variability in the approaches used to report the results in difficulty in comparing and generalizing the assessments.

References:

[12] R. K. Singh and U. Gupta (2018) “Social life cycle assessment in Indian steel sector: a case study”

[13] S. A. Hosseinijou, S. Mansour, and M. A. Shirazi (2014) “Social life cycle assessment for material selection: a case study of building materials”

[14] R. K. Foolmaun and T. Ramjeeawon (2013) “Comparative life cycle assessment and social life cycle assessment of used polyethylene terephthalate (PET) bottles in Mauritius”

Do you think that this articulated challenge to performing social impact assessments exists?

- Yes
- Maybe
- No
- I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- Always
- Sometimes
- Rarely
- Never
- I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- Extremely important
- Moderately important
- Slightly important
- Not important at all
- I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

Challenge #12: Selection of stakeholders relevant to the study

The use of stakeholder theory is significant in a number of frameworks found in the literature. This theory involves the determination of social impacts for different stakeholder groups. Over inclusion of stakeholders may result in prohibitive time and financial resource requirements to perform the study. Not including the right stakeholders may result in an incomplete social impact assessment.

Do you think that this articulated challenge to performing social impact assessments exists?

- ◯ Yes
- ◯ Maybe
- ◯ No
- ◯ I don't know.

How frequently have you encountered this challenge when performing social impact assessments?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ I don't perform these types of assessments

How important is addressing this challenge to the success of performing a social impact assessment?

- ○ Extremely important
- ○ Moderately important
- ○ Slightly important
- ○ Not important at all
- ○ I don't know.

Please provide any comments, additions or feedback you have related to this challenge.

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APPENDIX C DATABASE OF ARTICLES FROM SYSTEMATIC MAPPING

Table C1: Summary of articles selected through systematic map (n = 81).

Authors	Year	Title	Journal	Publication Type	Industry Sector	Case Study?
Agyekum, et al.	2016	Environmental and social life cycle assessment of bamboo bicycle frames made in Ghana	Journal of Cleaner Production	Academic Journal	Agriculture, Forestry, Fishing and Hunting, Transportation and Warehousing	Yes
Ajmal, et al.	2017	Conceptualizing and incorporating social sustainability in the business world	International Journal of Sustainable Development & World Ecology	Academic Journal	Management of Companies and Enterprises	No
Anaya, et al.	2018	Protected areas and territorial exclusion of traditional communities: analyzing the social impacts of environmental compensation strategies in Brazil	Ecology and Society	Academic Journal	Other services	Yes
Arcese, et al.	2016	Modeling Social Life Cycle Assessment framework for the Italian wine sector	Journal of Cleaner Production	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Arcese, et al.	2016	State of the art in S-LCA: integrating literature review and automatic text analysis	International Journal of Life Cycle Assessment	Academic Journal	Information	No
Arvidsson, et al.	2016	A method for human health impact assessment in social LCA: lessons from three case studies	International Journal of Life Cycle Assessment	Academic Journal	Transportation and Warehousing, Mining, Quarrying, Oil and Gas Extraction	Yes
Basta, et. al	2018	How are supply chains addressing their social responsibility dilemmas? Review of the last decade and a half	Corporate Social Responsibility and Environmental Management	Academic Journal	Professional, Scientific, and Technical Services	No
Benoit, et al.	2010	The Guidelines for Social Life Cycle Assessment of products: Just in time!	International Journal of Life Cycle Assessment	Academic Journal	Wholesale Trade	No
Bianchi and Ginell	2018	The social dimension in energy landscapes	City, Territory and Architecture	Academic Journal	Utilities, Health Care and Social Services	Yes
Chang, et al.	2018	Application Options of the Sustainable Child Development Index (SCDI)—Assessing the	International Journal of Environmental Research and Public Health	Academic Journal	NA	No

		Status of Sustainable Development and Establishing Social Impact Pathways				
Chang, et al.	2018	The Sustainable Child Development Index (SCDI) for Countries	Sustainability	Academic Journal	Professional, Scientific, and Technical Services	Yes
Chen and Holden	2016	Social life cycle assessment of average Irish dairy farm	International Journal of Life Cycle Assessment	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Corona, et al.	2017	Social Life Cycle Assessment of a Concentrated Solar Power Plant in Spain A Methodological Proposal	Journal of Industrial Ecology	Academic Journal	Utilities	Yes
Dubois-Iorgulescu, et al.	2016	How to define the system in social life cycle assessments? A critical review of the state of the art and identification of needed developments	International Journal of Life Cycle Assessment	Academic Journal	NA	No
Dunmade, et al.	2018	Lifecycle Impact Assessment of an Engineering Project Management Process – a SLCA Approach	Institute Of Physics Conf. Series: Materials Science and Engineering	Academic Journal	Manufacturing, Management of Companies and Enterprises	Yes
Ekener, et al.	2016	Addressing positive impacts in social LCA—discussing current and new approaches exemplified by the case of vehicle fuels	International Journal of Life Cycle Assessment	Academic Journal	Transportation and Warehousing	Yes
Falcone and Imbert	2018	Social Life Cycle Approach as a Tool for Promoting the Market Uptake of Bio-Based Products from a Consumer Perspective	Sustainability	Academic Journal	Agriculture, Forestry, Fishing and Hunting	No
Fedorova and Pongrácz	2019	Cumulative social effect assessment framework to evaluate the accumulation of social sustainability benefits of regional bioenergy value chains	Renewable Energy	Academic Journal	Utilities	Yes
Fontes, et al.	2016	Product social impact assessment	International Journal of Life Cycle Assessment	Academic Journal	Management of Companies and Enterprises	Yes
Garrido, et al.	2016	A literature review of type I SLCA—making the logic underlying methodological choices explicit	International Journal of Life Cycle Assessment	Academic Journal	NA	No
Gaviglio, et al.	2016	The social pillar of sustainability: a quantitative approach at the farm level	Agricultural and Food Economics	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Godskesen, et. al	2017	ASTA — A method for multi-criteria evaluation of water supply technologies to Assess the most Sustainable Alternative for Copenhagen	Science of the Total Environment	Academic Journal	Utilities	Yes
Gould, et al.	2016	Using social sustainability principles to analyze activities of the extraction lifecycle	Journal of Cleaner Production	Academic Journal	Management of Companies and	Yes

		phase: Learnings from designing support for concept selection			Enterprises, Transportation and Warehousing	
Grijalva, et al.	2016	Balance Scorecard Approach in Assessing Social Impact Performance Measures	Proceedings of the American Society for Engineering Management 2016 International Annual Conference	Academic Journal	Professional, Scientific, and Technical Services	No
Grubert	2016	Rigor in social life cycle assessment: improving the scientific grounding of SLCA	International Journal of Life Cycle Assessment	Academic Journal	Professional, Scientific, and Technical Services	No
Hoffenson, et al.	2013	A Multi-objective Tolerance Optimization Approach for Economic, Ecological, and Social Sustainability	20th CIRP International Conference on Life Cycle Engineering, Singapore, 2013	Academic Journal	Other services	Yes
Hossain, et al.	2017	Development of social sustainability assessment method and a comparative case study on assessing recycled construction materials	International Journal of Life Cycle Assessment	Academic Journal	Construction	Yes
Hosseinijou, et al.	2013	Social life cycle assessment for material selection: a case study of building materials	International Journal of Life Cycle Assessment	Academic Journal	Construction	Yes
Hussain, et al.	2018	Exploration of social sustainability in healthcare supply chain	Journal of Cleaner Production	Academic Journal	Management of Companies and Enterprises	Yes
Hutchins, et al.	2018	Development of indicators for the social dimension of sustainability in a U.S. business context	Journal of Cleaner Production	Academic Journal	Management of companies and enterprises	No
Ibáñez-Forés, et al.	2018	Assessing the social performance of municipal solid waste management systems in developing countries: Proposal of indicators and a case study	Ecological Indicators	Academic Journal	Administrative and Support and Waste Management and Remediation Services	Yes
Iofrida, et al.	2017	Why social life cycle assessment is struggling in development?	International Journal of Life Cycle Assessment	Academic Journal	NA	No
Janker, et al.	2018	Social sustainability in agriculture – A system-based framework	Journal of Rural Studies	Academic Journal	Agriculture, Forestry, Fishing and Hunting	No
Jiang, et al.	2018	A principal component analysis based three-dimensional sustainability assessment model to evaluate corporate sustainable performance	Journal of Cleaner Production	Academic Journal	Management of Companies and Enterprises	Yes

Kono, et al.	2018	Trade-Off between the Social and Environmental Performance of Green Concrete: The Case of 6 Countries	Sustainability	Academic Journal	Construction	Yes
Kuhnen and Hahn	2017	Indicators in Social Life Cycle Assessment A Review of Frameworks, Theories, and Empirical Experience	Journal of Industrial Ecology	Academic Journal	NA	No
Lucchetti, et al.	2018	S-LCA applications: a case studies analysis	2018 International Conference Series on Life Cycle Assessment	Academic Journal	NA	No
Macombe, et al.	2016	Extended community of peers and robustness of social LCA	International Journal of Life Cycle Assessment	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Odile, et al.	2019	Introduction to evaluating energy justice across the life cycle: A social life cycle assessment approach	Applied Energy	Academic Journal	Utilities	Yes
Pack, et al.	2018	Social Impact In Product Design, An Exploration Of Current Industry Practices	Proceedings of the ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference	Academic Journal	NA	No
Pelletier	2018	Social Sustainability Assessment of Canadian Egg Production Facilities: Methods, Analysis, and Recommendations	Sustainability	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Pelletier, et al.	2016	Social sustainability in trade and development policy	International Journal of Life Cycle Assessment	Academic Journal	Wholesale Trade	Yes
Peruzzini and Pellicciari	2018	Application of Early Sustainability Assessment to Support the Design of Industrial Systems	Industrial Engineering & Management Systems	Academic Journal	Management of Companies and Enterprises	Yes
Peruzzini, et al.	2017	A social life cycle assessment methodology for smart manufacturing: The case of study of a kitchen sink	Journal of Industrial Information Integration	Academic Journal	Manufacturing	Yes
Pesce, et al.	2018	Selecting sustainable alternatives for cruise ships in Venice using multi- criteria decision analysis	Science of the Total Environment	Academic Journal	Transportation and Warehousing	Yes
Petti, et al.	2016	Systematic literature review in social life cycle assessment	International Journal of Life Cycle Assessment	Academic Journal	NA	No
Popovic, et al.	2018	Quantitative indicators for social sustainability assessment of supply chains	Journal of Cleaner Production	Academic Journal	Manufacturing	No

Prasara and Gheewala	2017	Applying Social Life Cycle Assessment in the Thai Sugar Industry: Challenges from the field	Journal of Cleaner Production	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Rafiaani,et al.	2017	Social sustainability assessments in the biobased economy: Towards a systemic approach	Renewable and Sustainable Energy Reviews	Academic Journal	Agriculture, Forestry, Fishing and Hunting	No
Rainock, et al.	2018	The social impacts of products: a review	Impact Assessment and Project Appraisal	Academic Journal	NA	No
Reitinger, et al.	2011	A conceptual framework for impact assessment within SLCA	International Journal of Life Cycle Assessment	Academic Journal	NA	Yes
Richter, et. al	2018	A method for economic input-output social impact analysis with application to U.S. advanced manufacturing	Journal of Cleaner Production	Academic Journal	Management of companies and enterprises	Yes
Sakellariou	2016	A historical perspective on the engineering ideologies of sustainability: the case of SLCA	International Journal of Life Cycle Assessment	Academic Journal	NA	No
Santos, et al.	2019	Social life cycle analysis as a tool for sustainable management of illegal waste dumping in municipal services	Journal of Cleaner Production	Academic Journal	Administrative and Support and Waste Management and Remediation Services	Yes
Shang, et al.	2018	Ontology based social life cycle assessment for product development	Advances in Mechanical Engineering	Academic Journal	Construction	Yes
Shemfe, et al.	2018	Social Hotspot Analysis and Trade Policy Implications of the Use of Bioelectrochemical Systems for Resource Recovery from Wastewater	Sustainability	Academic Journal	Utilities	Yes
Siebert, et. al	2017	Social life cycle assessment indices and indicators to monitor the social implications of wood-based products	Journal of Cleaner Production	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Siebert, et. al	2018	How not to compare apples and oranges: Generate context-specific performance reference points for a social life cycle assessment model	Journal of Cleaner Production	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Siebert, et. al	2016	Social life cycle assessment: in pursuit of a framework for assessing wood-based products from bioeconomy regions in Germany	International Journal of Life Cycle Assessment	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Sierra, et al.	2018	A review of multi-criteria assessment of the social sustainability of infrastructures	Journal of Cleaner Production	Academic Journal	Construction	No
Sierra, et al.	2017	Method for estimating the social sustainability of infrastructure projects	Environmental Impact Assessment Review	Academic Journal	Construction	Yes

Singh and Gupta	2017	Social life cycle assessment in Indian steel sector: a case study	International Journal of Life Cycle Assessment	Academic Journal	Mining, Quarrying, Oil and Gas Extraction, Manufacturing	Yes
Sousa-Zomer, et al.	2015	The main challenges for social life cycle assessment (SLCA) to support the social impacts analysis of product-service systems	International Journal of Life Cycle Assessment	Academic Journal	Utilities	Yes
Spierling, et al.	2018	Bio-based plastics - A review of environmental, social and economic impact assessments	Journal of Cleaner Production	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Subramanian and Yung	2018	Modeling Social Life Cycle Assessment framework for an electronic screen product e A case study of an integrated desktop computer	Journal of Cleaner Production	Academic Journal	Manufacturing	Yes
Suckling and Lee	2017	Integrating Environmental and Social Life Cycle Assessment	Journal of Industrial Ecology	Academic Journal	Manufacturing	Yes
Sureau, et al.	2017	Social life-cycle assessment frameworks: a review of criteria and indicators proposed to assess social and socioeconomic impacts	International Journal of Life Cycle Assessment	Academic Journal	NA	no
Teah and Onuki	2017	Support Phosphorus Recycling Policy with Social Life Cycle Assessment: A Case of Japan	Sustainability	Academic Journal	Mining, Quarrying, Oil and Gas Extraction	Yes
Tecco, et al.	2016	Innovation strategies in a fruit growers association impacts assessment by using combined LCA and s-LCA methodologies	Science of the Total Environment	Academic Journal	Agriculture, Forestry, Fishing and Hunting	Yes
Telles do Carmo, et al.	2017	Addressing uncertain scoring and weighting factors in social life cycle assessment	International Journal of Life Cycle Assessment	Academic Journal	NA	No
Traverso, et al.	2016	Towards social life cycle assessment: a quantitative product social impact assessment	International Journal of Life Cycle Assessment	Academic Journal	Manufacturing	Yes
van der Velden and Vogtländer	2017	Monetisation of external socio-economic costs of industrial production: A social-LCA-based case of clothing production	Journal of Cleaner Production	Academic Journal	Manufacturing	Yes
van Haaster, et. al	2016	Development of a methodological framework for social life-cycle assessment of novel technologies	International Journal of Life Cycle Assessment	Academic Journal, Roundtable	Utilities, Administrative and Support and Waste Management and Remediation Services	Yes
Wang, et al.	2016	An analytic framework for social life cycle impact assessment—part 1: methodology	International Journal of Life Cycle Assessment	Academic Journal	Manufacturing	No
Wang, et al.	2017	Assessing Social Sustainability for Biofuel Supply Chains: The Case of Aviation Biofuel in Brazil	2017 IEEE Conference on Technologies for Sustainability (SusTech)	Academic Journal	Transportation and Warehousing	Yes

Yıldız, et. al	2017	Social life cycle assessment of different packaging waste collection system	Resources, Conservation & Recycling	Academic Journal	Administrative and Support and Waste Management and Remediation Services	Yes
Zanchi, et al.	2016	Analysis of the main elements affecting social LCA applications: challenges for the automotive sector	International Journal of Life Cycle Assessment	Academic Journal	Manufacturing	Yes

Table C2: Summary of case studies (n = 49).

Authors	Year	Title	Journal	Timing	Study Scope	LCA Based?	Industry Sector
Agyekum, et al.	2016	Environmental and social life cycle assessment of bamboo bicycle frames made in Ghana	Journal of Cleaner Production	Post	Comparison	Yes	Agriculture and Transportation
Anaya, et al.	2018	Protected areas and territorial exclusion of traditional communities: analyzing the social impacts of environmental compensation strategies in Brazil	Ecology and Society	Post	Informative	No	Other
Arcese, et al.	2016	Modeling Social Life Cycle Assessment framework for the Italian wine sector	Journal of Cleaner Production	Post	Informative	Yes	Information
Arvidsson, et al.	2016	A method for human health impact assessment in social LCA: lessons from three case studies	International Journal of Life Cycle Assessment	Post	Comparison, Informative	Yes	Transportation and Warehousing, Mining, Quarrying, and Oil and Gas Extraction
Bianchi and Ginell	2018	The social dimension in energy landscapes	City, Territory and Architecture	Post	Informative	No	Utilities
Chang, et al.	2018	The Sustainable Child Development Index (SCDI) for Countries	Sustainability	Post	Informative	No	Professional, Scientific, and Technical Services
Chen and Holden	2016	Social life cycle assessment of average Irish dairy farm	International Journal of Life Cycle Assessment	Post	Informative	Yes	Agriculture, Forestry, Fishing and Hunting
Corona, et al.	2017	Social Life Cycle Assessment of a Concentrated Solar Power	Journal of Industrial Ecology	Pre	Informative	Yes	Utilities

		Plant in Spain A Methodological Proposal					
Dunmade, et al.	2018	Lifecycle Impact Assessment of an Engineering Project Management Process – a SLCA Approach	Institute Of Physics Conf. Series: Materials Science and Engineering	Post	Informative	Yes	Manufacturing, Management of Companies and Enterprises
Ekener, et al.	2016	Addressing positive impacts in social LCA—discussing current and new approaches exemplified by the case of vehicle fuels	International Journal of Life Cycle Assessment	Pre	Comparison	Yes	Transportation and Warehousing
Fedorova and Pongrácz	2019	Cumulative social effect assessment framework to evaluate the accumulation of social sustainability benefits of regional bioenergy value chains	Renewable Energy	Post	Informative	Yes	Utilities
Gaviglio, et al.	2016	The social pillar of sustainability: a quantitative approach at the farm level	Agricultural and Food Economics	Post	Comparison	No	Agriculture, Forestry, Fishing and Hunting
Godskesen, et. al	2017	ASTA — A method for multi-criteria evaluation of water supply technologies to Assess the most Sustainable Alternative for Copenhagen	Science of the Total Environment	Pre, Post	Comparison	No	Utilities
Gould, et al.	2016	Using social sustainability principles to analyze activities of the extraction lifecycle phase: Learnings from designing support for concept selection	Journal of Cleaner Production	Pre	Comparison	Yes	Management of Companies and Enterprises, Transportation and Warehousing
Hede, et al.	2013	Incorporating sustainability in decision-making for medical device development	Technology in Society	Pre	Comparison	Yes	Professional, Scientific,

							and Technical Services
Hoffenson, et al.	2013	A Multi-objective Tolerance Optimization Approach for Economic, Ecological, and Social Sustainability	20th CIRP International Conference on Life Cycle Engineering, Singapore, 2013	Pre	Comparison	Yes	Other
Holger, et al.	2017	The social footprint of hydrogen production - A Social Life Cycle Assessment (S-LCA) of alkaline water electrolysis	Energy Procedia	Pre	Informative	Yes	Utilities
Hossain, et al.	2017	Development of social sustainability assessment method and a comparative case study on assessing recycled construction materials	International Journal of Life Cycle Assessment	Post	Comparison	Yes	Constructio n
Hosseinijou , et al.	2013	Social life cycle assessment for material selection: a case study of building materials	International Journal of Life Cycle Assessment	Post	Comparison	Yes	Constructio n
Hussain, et al.	2018	Exploration of social sustainability in healthcare supply chain	Journal of Cleaner Production	Post	Informative	No	Health care service
Ibáñez-Forés, et al.	2018	Assessing the social performance of municipal solid waste management systems in developing countries: Proposal of indicators and a case study	Ecological Indicators	Post	Comparison	Yes	Administrat ive and Support and Waste Manageme nt and Remediatio n Services
Jiang, et al.	2018	A principal component analysis based three-dimensional sustainability assessment model to evaluate corporate sustainable performance	Journal of Cleaner Production	Post	Informative	Yes	Manageme nt of Companies and Enterprises
Kono, et al.	2018	Trade-Off between the Social and Environmental Performance of Green	Sustainability	Post	Comparison, Enhancement	Yes	Constructio n

		Concrete: The Case of 6 Countries					
Odile, et al.	2019	Introduction to evaluating energy justice across the life cycle: A social life cycle assessment approach	Applied Energy	Pre	Comparison, Informative, Enhancement	Yes	Utilities
Pelletier	2018	Social Sustainability Assessment of Canadian Egg Production Facilities: Methods, Analysis, and Recommendations	Sustainability	Post	Informative	Yes	Agriculture
Pelletier, et al.	2016	Social sustainability in trade and development policy	International Journal of Life Cycle Assessment	Post	Informative	Yes	Wholesale Trade
Peruzzini and Pellicciari	2018	Application of Early Sustainability Assessment to Support the Design of Industrial Systems	Industrial Engineering & Management Systems	Pre	Comparison, Informative	Yes	Manufacturing, Management of Companies and Enterprises
Peruzzini, et al.	2017	A social life cycle assessment methodology for smart manufacturing: The case of study of a kitchen sink	Journal of Industrial Information Integration	Post	Informative	Yes	Manufacturing
Pesce, et al.	2018	Selecting sustainable alternatives for cruise ships in Venice using multi- criteria decision analysis	Science of the Total Environment	Pre	Comparison	Yes	Transportation
Prasara and Gheewala	2017	Applying Social Life Cycle Assessment in the Thai Sugar Industry: Challenges from the field	Journal of Cleaner Production	Post	Informative	Yes	Agriculture, Forestry, Fishing and Hunting
Richter, et. al	2018	A method for economic input-output social impact analysis with application to U.S. advanced manufacturing	Journal of Cleaner Production	Post	Comparison	No	Manufacturing
Santos, et al.	2019	Social life cycle analysis as a tool for sustainable management of illegal waste dumping in municipal services	Journal of Cleaner Production	Post	Informative	Yes	Administrative and Support and Waste Manageme

							nt and Remediation Services
Schlör, et al.	2018	The energy-mineral-society nexus – A social LCA model	Applied Energy	Post	Comparison	Yes	Mining, Quarrying, and Oil and Gas Extraction
Shang, et al.	2018	Ontology based social life cycle assessment for product development	Advances in Mechanical Engineering	Post	Informative	Yes	Construction
Shemfe, et al.	2018	Social Hotspot Analysis and Trade Policy Implications of the Use of Bioelectrochemical Systems for Resource Recovery from Wastewater	Sustainability	Pre	Informative	Yes	Utilities
Siebert, et. al	2018	How not to compare apples and oranges: Generate context-specific performance reference points for a social life cycle assessment model	Journal of Cleaner Production	Pre, Post	Informative	Yes	Agriculture, Forestry, Fishing and Hunting
Siebert, et. al	2016	Social life cycle assessment: in pursuit of a framework for assessing wood-based products from bioeconomy regions in Germany	International Journal of Life Cycle Assessment	Post	Informative	Yes	Agriculture, Forestry, Fishing and Hunting
Sierra, et al.	2017	Method for estimating the social sustainability of infrastructure projects	Environmental Impact Assessment Review	Pre	Informative, Enhancement	Yes	Construction
Singh and Gupta	2017	Social life cycle assessment in Indian steel sector: a case study	International Journal of Life Cycle Assessment	Post	Informative	Yes	Manufacturing
Spierling, et al.	2018	Bio-based plastics - A review of environmental, social and economic impact assessments	Journal of Cleaner Production	Pre	Comparison	Yes	Agriculture, Forestry, Fishing and Hunting
Subramanian and Yung	2018	Modeling Social Life Cycle Assessment framework for an electronic screen product e A case study of an integrated desktop computer	Journal of Cleaner Production	Post	Informative	Yes	Manufacturing

Teah and Onuki	2017	Support Phosphorus Recycling Policy with Social Life Cycle Assessment: A Case of Japan	Sustainability	Pre	Comparison	Yes	Mining, Quarrying, and Oil and Gas Extraction
Tecco, et al.	2016	Innovation strategies in a fruit growers association impacts assessment by using combined LCA and s-LCA methodologies	Science of the Total Environment	Pre	Informative	Yes	Agriculture , Forestry, Fishing and Hunting
Traverso, et al.	2016	Towards social life cycle assessment: a quantitative product social impact assessment	International Journal of Life Cycle Assessment	Post	Informative	Yes	Manufactur ing
van der Velden and Vogtländer	2017	Monetisation of external socio-economic costs of industrial production: A social-LCA-based case of clothing production	Journal of Cleaner Production	Post	Informative	Yes	Manufactur ing
van Haaster, et. al	2016	Development of a methodological framework for social life-cycle assessment of novel technologies	International Journal of Life Cycle Assessment	Pre	Enhancement	Yes	Utilities
Wang, et al.	2017	Assessing Social Sustainability for Biofuel Supply Chains: The Case of Aviation Biofuel in Brazil	2017 IEEE Conference on Technologies for Sustainability (SusTech)	Post	Comparison	Yes	Transportat ion
Yıldız, et. al	2017	Social life cycle assessment of different packaging waste collection system	Resources, Conservation & Recycling	Post	Informative	Yes	Administrat ive and Support and Waste Manageme nt and Remediatio n Services
Zanchi, et al.	2016	Analysis of the main elements affecting social LCA applications: challenges for the automotive sector	International Journal of Life Cycle Assessment	Pre, Post	Informative	No	Transportat ion

APPENDIX D DATABASE OF IMPACT ASSESSMENT METHODOLOGIES

Method/Article name	Stakeholder theory	Functional unit	Primary/ secondary data	Quantitative	Qualitative	Comments
A Multi-objective Tolerance Optimization Approach for Economic, Ecological, and Social Sustainability [46]	✓		Secondary	✓		Number
Social Sustainability Grading Model [125]	✓		Primary	✓	✓	5-level scale Likert analysis
Environmental and social life cycle assessment of bamboo bicycle frames made in Ghana [31]	✓	✓ (1 average bicycle frame)	Primary	✓	✓	Score of 1-5 for companies
Detailed Inventory Phase [122]	✓		Primary		✓	7 steps that start with Y/N questions
Application of a methodology for the social life cycle assessment of recycling systems in low income countries: three Peruvian case studies [191]	✓	✓ (Amount of waste collected in 1 house for 1 year)	Primary		✓	Score of 0 or 1
S-LCA applications: a case studies [23]	✓	✓ (1 company)	Primary		✓	Yes/no answers
Social life cycle assessment of different packaging waste collection system [192]	✓	✓ (Production of 1 L of virgin oil)	Primary	✓	✓	1 and 0 for qualitative data and Likert scale for the other data
Introducing the UNEP/SETAC methodological sheets for subcategories of social LCA [22]	✓	✓ (1 laptop)	Both	✓	✓	1-6 per indicators
Social life cycle assessment of average Irish dairy farm [151]	✓	✓ (1 kg of energy corrected milk)	Both	✓	✓	Impact assessment was score between 1 and 7; indicators are normalized between -1, 1 or 0,1
Potential methods and approaches to assess social impacts associated with food safety issues [193]	✓	✓ (1 company)	Both		✓	Indicators are scored between 1-3 and a final score is given between 0-1 within 1 of 5 slots

Comparative life cycle assessment and social life cycle assessment of used polyethylene terephthalate (PET) bottles in Mauritius[169]	✓	✓ (Disposal of 1 tonne of used PET bottles)	Both	✓	✓	Scoring is done between 0-4 (5 slots) for each indicator
Socio Eco Costs method [129]	✓		Both	✓		Quantitative formulas with $ units
Generic Human Health Method [133]	✓	✓ (one catalytic converter)	Both	✓		The method uses the DALY to determine the human health impacts
Social life cycle assessment of different packaging waste collection system [192]	✓	✓ (total mixed packaging waste collected by municipality in the year 2012)	Both		✓	All questionnaires results are converted to values of 0, 0.5 or 1; values are normalized between 0-1 based on the min and max values of the indicator
Development of a New Methodology for Impact Assessment of SLCA [194]	✓	✓	Both	✓	✓	Quantification process is different per the indicator type; values are changed into % and then given a score between 1-5 based on where the fit
Social life cycle assessment of palm oil biodiesel: a case study in Jambi Province of Indonesia [195]	✓		Primary		✓	Likert scale values between 1 to 7
Socioeconomic LCA of milk production in Canada [176]	✓	✓ (1kg of fat from corrected milk)	Both		✓	Indicator values are given a risky, compliant, proactive or committed behavior
An analytic framework for social life cycle impact assessment—part 1: methodology [130]	✓		Both	✓		Method only uses quant and semi-quant indicators (score of 0, 0.5 and 1); values are changed to % and then between 1-5;
Social Life Cycle Assessment of a Concentrated Solar Power Plant in Spain [134]	✓	✓(1 MWh)	Both	✓	✓	7 steps and given a score between -2 and +2

Cumulative social effect assessment framework [137]	✓		Both	✓	✓	Impacts are done as one of three levels (high, average or low positive or negative impacts) for each indicator
ASTA Framework [156]	✓	✓	Both	✓	✓(quantified using AHP)	AHP used for quantification of qualitative values; ROM used for weighting of sustainability dimensions; values were normalized to 0-1
Assessing the social performance of municipal solid waste management systems in developing countries: Proposal of indicators and a case study [141]	✓		Both	✓	✓	Scale from 0-100 for all metrics and then change to % per subcategory
A principal component analysis based three-dimensional sustainability assessment model to evaluate corporate sustainable performance [157]	✓	✓ (normalized FU: unit industrial output value)	Both	✓	✓	10 steps; Principle Component Analysis (PCA) is used for quantification and aggregation
Sustainable Child Index [182]	✓		Secondary	✓		All values are normalized to a scale between 0-1 and then aggregated
PROSUITE [107]	✓	✓ (1 kWh of electricity)	Both	✓	✓	Quantitative metrics are aggregated; metrics are normalized using global data;
Multi-criteria Decision Analysis [158]	✓	✓ (1 ship route)	Both	✓	✓	Aggregation is performed to a single index; MCDA weights are used;
Applying Social Life Cycle Assessment in the Thai Sugar Industry: Challenges from the field [144]	✓	✓ (1 tonne of sugar)	Both		✓	Answers were changed into % and then aggregated

Greenzee model [145]	✓	✓ (1 kg of biodiesel)	Primary	✓		Results are $; results are either positive, negative or neutral
RESPONSA [124]	✓	✓ (1 kg of product)	Primary	✓	✓	Indicators all have different scores but then are normalized
Social life cycle assessment for material selection: a case study of building materials [1]	✓	✓ (amount of concrete and steel for 1 m^2 of floor area)	Both	✓	✓	Consists of 5 steps: form problem hierarchy, pairwise comparison, inconsistency analysis, calculate final score and sensitivity analysis; scores are averaged per subcategory
Modeling Social Life Cycle Assessment framework for an electronic screen product e A case study of an integrated desktop computer [152]	✓	✓ (HP all in one computer)	Both	✓	✓	All values are between 1-3; weighting done using Likert scale
Support Phosphorus Recycling Policy with Social Life Cycle Assessment: A Case of Japan [177]	✓	✓ (1 kg of Phosphorus)	Secondary	✓		SHDB was used and multiplied by weight values
Social Sustainability Assessment of Canadian Egg Production Facilities: Methods, Analysis, and Recommendations [154]	✓	✓ (1000 egg facility worker hours)	Both	✓	✓	1 of 4 color code levels are given to activities
Product Social Impact Assessment [6]	✓	✓	Both	✓	✓	The scores for each indicator are given based on 1 of 5 scoring scale values: +2 ideal performance, +1 progress beyond compliance, 0 compliance with local laws, -1 non-compliant situation but improving, -2 no-data or non-compliant situation

APPENDIX E DATABASE OF IMPACT INDICATORS

Indicator name	Impact category	Lifecycle Stage	Stakeholder Group	Indicator Type	Indicator Level	Paper #	Application
EC10 Debt asset ratio	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EC11 R&D expenditure	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EC2 Total industrial output value	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EC3 Total sales	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EC4 Total profit	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EC5 Current assets turnover	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EC6 Net working capital	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EC7 Rate of return on common stockholders’	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China

equity EC8 Ratio of profits to cost							
EC9 Exports proportion of total sales	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
Total assets	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
% Consumers complaints	Feedback mechanism	Usage	Consumer	Quantitative	Sector	[38]	Italian wine sector
% Regular and loyal costumers	Feedback mechanism	Usage	Consumer	Quantitative	Sector	[38]	Italian wine sector
Acceptance and willingness to collect glass bottle (Amount of glass bottles collected (%))	End of life responsibility	Usage	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector
Alcohol related diseases (cerebrovascular diseases, chronic liver diseases, cirrhosis, ulcers of stomach and duodenum)	Health and safety	Usage	Consumer	Quantitative	Sector	[38]	Italian wine sector

Awareness on health issues related to alcohol usage	Transparency	Usage	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector
Consumer/product responsibility	Community development	All stages	Consumer	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Existence of national entities ensuring consumers rights	Feedback mechanism	Usage	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector
Guarantee of respect of quality requirement	Health and safety	Usage	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector
Lives lost in car accidents for alcohol abuse	Health and safety	Usage	Consumer	Quantitative	Sector	[38]	Italian wine sector
Market-surveys carried out in accordance with Privacy Code	Consumer privacy	Access to market	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector
Number of complaints identified	Service satisfaction	All stages	Consumer	Quantitative	Company	[192]	Packaging waste collection systems
Presence of a mechanism for customers to provide feedback	Feedback mechanism	Usage	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector

Presence of Traceability Systems	Transparency	Usage	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector
Road traffic accidents involving injuries (WHO, 2013)	Health and safety	Usage	Consumer	Quantitative	Sector	[38]	Italian wine sector
Use of alcohol under 18 years old	Health and safety	Usage	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector
Well-defined and clear information about the product, the company and company's suppliers	Transparency	Access to market	Consumer	Semi-quantitative	Sector	[38]	Italian wine sector
S8 Customer satisfaction	Social Indicators	All stages	Consumers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
Scale: What is the relative burden of penalties associated with late or missing payments?	Transparency	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Are all charges and possible penalties transparently described as part of a consumer’s electric bill?	Transparency	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

Yes/no: Are the capital costs prohibitive for different populations to gain access to lower operational costs for electricity provision?	Equal opportunities	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Do consumers have a mechanism to provide feedback to their utility?	Feedback mechanism	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Do electricity consumers have a choice in the utility company or in generation methods used by their utility?	Fair competition	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Do electricity consumers have free access to objective information about energy use and sources of electricity?	Transparency	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Does the burden of penalties significantly differ across populations served by the utility?	Equality	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

Yes/no: Does the cost of electricity relative to household income significantly differ across populations served by the utility?	Equality	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Does the electric utility act to address consumer feedback or complaints?	Feedback mechanism	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Does the number of brownouts over time differ across populations served by the utility?	Equality	Electrical power generation, transportation and distribution	Consumers	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Customer satisfaction	Social-human	Use	Customer	Quantitative	Product	[16]	Manufacturing
Customer satisfaction	Feedback	All stages	Customer	Quantitative	Country	[150]	Indian steel sector industry
Health and safety of the product at the use phase	Social-human	Use	Customer	Quantitative	Product	[16]	Manufacturing

Incidents of consumer health and safety	Consumer health and safety	All stages	Customer	Quantitative	Sector, company	[150]	Indian steel sector industry
Resource use during the use phase	Ecological impact	Use	Customer	Quantitative	Product	[46]	Mobile phone
Local authorities' engagement in improving the comfort and collecting effort for the citizens (Frequency of organic bin emptying, % public space used % private space used)	Community engagement	Usage	Local community	Quantitative	Sector	[38]	Italian wine sector
% IT use	Access to immaterial resources	Agriculture	Local community	Quantitative	Sector	[38]	Italian wine sector
% Of workers employed from factory location	Local employment	Production, processing	Local community	Quantitative	Community	[31]	Bicycle frame
% Of workers employed from resource location	Local employment	Production, processing	Local community	Quantitative	Community	[31]	Bicycle frame
Access to Hospital Beds	Health	Extraction	Local community	Quantitative	Country	[44]	Aerospace industry
Access to Improved Drinking Water	Health	Extraction	Local community	Quantitative	Country	[44]	Aerospace industry

Access to Improved Sanitation	Health	Extraction	Local community	Quantitative	Country	[44]	Aerospace industry
Additional activities related to development of local economy as generated from or associated with the processes to produce the product in question could be quantitative (funds allocated to specific activities) or quantitative (presentation of initiatives).	Local economic development	All stages	Local community	Semi-quantitative	Company	[135]	Vehicular fuels
Awareness of resource owner on the use of the resource before and after pricing	Respect of Local's People Rights	Production, processing	Local Community	Qualitative	Community	[31]	Bicycle frame
Community welfare	Economic impact	All stages	Local community	Quantitative	Region	[155]	Medical devices
Cost of environmental impact on human health/ECM (derived from ELCA model)	Safe and healthy living conditions	Production, processing	Local community	Quantitative (functional-unit related)	Farm (company)	[151]	Irish Dairy Farm
Cultural heritage	Community development	All stages	Local community	Quantitative, semi-	Company	[196]	Business and corporation applications for decision making at the management level.

				quantitative, qualitative			
Current average accessibility	Property and habitability	All stages	Local community	Quantitative	Community	[197]	Construction or infrastructure development
Current frequency of public transport	Property and habitability	All stages	Local community	Quantitative	Community	[197]	Construction or infrastructure development
Direct economic impacts (Total amount of direct investment)	Community well-being	All stages	Local community	Quantitative	Region	[137]	Bioenergy industry
Employment (Number of new jobs created)	Community well-being	All stages	Local community	Quantitative	Region	[137]	Bioenergy industry
Expropriation	Property and habitability	All stages	Local community	Qualitative	Community	[197]	Construction or infrastructure development
Feel of community engagement	Community engagement	Production, processing	Local community	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Good governance	Community development	All stages	Local community	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Human Health communicable diseases	Health	Extraction	Local community	Quantitative	Country	[44]	Aerospace industry

Human Health Non-communicable diseases and other health risks	Health	Extraction	Local community	Quantitative	Country	[44]	Aerospace industry
Human rights	Community development	All stages	Local community	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Human rights complaints	Respect of indigenous rights	All stages	Local community	Quantitative	Sector, company	[150]	Indian steel sector industry
Human rights issues faced by indigenous people		Production, processing	Local community	Quantitative (functional-unit related)	Country	[162]	Green concrete assessment in 6 countries
If the service affects the local community's health and safe living conditions or not	Health and safe living conditions	All stages	Local community	Semi-quantitative	Company	[192]	Packaging waste collection systems
If the service endangers the local community's secure living conditions or not	Secure living conditions	All stages	Local community	Semi-quantitative	Company	[192]	Packaging waste collection systems
Income distribution	Impartiality	Extraction	Local community	Quantitative	Country	[44]	Aerospace industry

Indigenous rights	Impartiality	Extraction	Local community	Quantitative	Country	[44]	Aerospace industry
Indigenous rights	Community development	All stages	Local community	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Levels of industrial water use	Access to material resources	Transformation	Local community	Quantitative	Sector	[38]	Italian wine sector
Levels of water use	Access to material resources	Agriculture	Local community	Quantitative	Sector	[38]	Italian wine sector
Local authorities' engagement in improving the comfort and collecting effort for the citizens	Community engagement	Usage	Local community	Quantitative	Sector	[38]	Italian wine sector
Low to very high level of commitment. Qualitative assessment turned into semi-quantitative.	Community engagement	All stages	Local community	Semi-quantitative	Region, company	[136]	Vehicular fuels
Low to very high level of contribution. Qualitative assessment	Infrastructure development	All stages	Local community	Semi-quantitative	Region, company	[136]	Vehicular fuels

turned into semi-quantitative							
Manure spread and storage technique	Respect indigenous right	Production, processing	Local community	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Max historic value paid for right of way	Property and habitability	All stages	Local community	Quantitative	Region	[197]	Construction or infrastructure development
Max tolerable affected properties	Property and habitability	All stages	Local community	Quantitative	Community	[197]	Construction or infrastructure development
Means of participation	Citizen participation	All stages	Local community	Qualitative	Community	[197]	Construction or infrastructure development
No access to improved drinking water	Health and safety	All stages	Local community	Semi-quantitative, quantitative	Country	[160]	Hydrogen energy production (electricity plant)
No access to improved sanitation	Health and safety	All stages	Local community	Semi-quantitative, quantitative	Country	[160]	Hydrogen energy production (electricity plant)
Number of jobs lost during the reporting period		Production, processing, end of life	Local Community	Quantitative	Company	[192]	Packaging waste collection systems
Number of local jobs created in relation to	Local employment	All stages	Local community	Quantitative	Region	[136]	Vehicular fuels

final product energy unit (MJ)							
Number of new jobs created	Employment	Production, processing, end of life	Local Community	Quantitative	Company	[192]	Packaging waste collection systems
Numbers of people who support the system	Social acceptability	All stages	Local Community	Quantitative	Company	[192]	Packaging waste collection systems
Organizational procedures for integrating migrant workers into the community	Delocalization and migration	Agriculture	Local community	Semi-quantitative	Sector	[38]	Italian wine sector
Payment for using resources	Respect of Local's People Rights	Production, processing	Local Community	Qualitative	Community	[31]	Bicycle frame
Percentage of spending on locally based suppliers	Local employment	Agriculture	Local community	Quantitative	Sector	[38]	Italian wine sector
Percentage of spending on locally based suppliers	Local employment	Transformation	Local community	Quantitative	Sector	[38]	Italian wine sector
Percentage of workforce hired in Municipalities where the facilities for	Local employment	Transformation	Local community	Quantitative	Sector	[38]	Italian wine sector

producing, bottling and storage the wine are settled							
Percentage of workforce hired in Municipalities where the sales points are settled	Local employment	Access to market	Local community	Quantitative	Sector	[38]	Italian wine sector
Percentage of workforce hired in Municipalities where vineyards are settled	Local employment	Agriculture	Local community	Quantitative	Sector	[38]	Italian wine sector
Permission for using resources	Respect of Local's People Rights	Production, processing	Local Community	Qualitative	Community	[31]	Bicycle frame
Population living on degraded land	Safe and healthy living conditions	Agriculture	Local community	Quantitative	Sector	[38]	Italian wine sector
Presence of Indigenous population	Respect of indigenous rights	Production, processing	Local community	Quantitative (functional-unit related)	Country	[162]	Green concrete assessment in 6 countries
Presence of quality certificates of origin for local products	Area reputation	Access to market	Local community	Semi-quantitative	Sector	[38]	Italian wine sector

Product responsibility (justice, fairness, equity, human rights, public service policy)	Social-human	Use, end of life	Local community	Quantitative	Product	[16]	Manufacturing
Quantification of the health and safety impacts on local community members by the activities of the company	Health and safety	All stages	Local Community	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Quantification of the number and duration of protests of the company and the number of protesters that are from the local community	Protest	All stages	Local Community	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Quantification of the number of meetings with individual community groups or leaders prior to a company's decision-making that could affect a local community	Community engagement	All stages	Local Community	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Quantification of the percentage of the resources in an area, including land, used by the company that are	Respect of Local's People Rights	All stages	Local Community	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

owned by members of the local community							
Quantification of the percentage of the workers who reside in the local community and who did not migrate to the local community for employment at the company	Local employment	All stages	Local Community	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Regional economic development (Number of regional actors Involved in production supply chain)	Community well-being	All stages	Local community	Quantitative	Region	[137]	Bioenergy industry
Scale: extent to which the activities of a company either positively or negatively affect the local community's sense of place and cultural heritage	Cultural heritage	All stages	Local Community	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Scale: the extent to which relocation of local community members is involuntary	Delocalization and migration	All stages	Local Community	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

Scale: the extent to which the local community was involved and recognized in the decision to begin operations in an area	Community engagement	All stages	Local Community	Semi-quantitative	Region, company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Share of dairy employees in agricultural employee	Local employment	Production, processing	Local community	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Social involvement	Community development	All stages	Local community	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Soil quality	Access to material resources	Agriculture	Local community	Qualitative	Sector	[38]	Italian wine sector
Soil quality	Access to material resources	Transformation	Local community	Qualitative	Sector	[38]	Italian wine sector
Statutory requirement for protection /guideline for repair and maintenance	Natural and cultural heritage	Production, processing	Local community	Semi-quantitative	Farm (company)	[151]	Irish Dairy Farm
The level of exposure of the local community to injuries, harm and	Physical wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant

contagious disease as a result of project							
The project encouraged creativity and Stimulated mental activities of the members of the local community	Intellectual wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project encouraged members of The local community to be committed to their beliefs	Spiritual well being	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project encouraged members of The local community to cultivate optimistic attitude towards the municipality	Emotional wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project enhanced community Members' freedom to be who they are, Thereby preserving their culture and	Spiritual well being	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant

Tradition							
The project enhanced freedom of Expression by community members	Emotional wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project facilitated communal effort to conserve material, energy and water resources (i.e. Reduce, reuse, recycle) thereby minimizing harm to the environment	Environmental wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project facilitated community's Openness to change and to learning	Sense of community wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project fostered good communication and rapport among the members and leaders of the local community	Social well being	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant

The project increased the community Members' satisfaction /pleasure with the Changes taking place in their local Community	Sense of community wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project increased the local Community's awareness regarding Effects of its activities on the physical Environment	Environmental wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project made the local Community to be up-to-date by such facility being in their domain. It also fosters the participation of community members in activities that arouse their curiosity	Intellectual wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant

The project propelled community Members to get involved, share their Talents and skills, and contribute to the local community	Social well being	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
The project provided the local community increased opportunities to grow and to overcome its challenges	Spiritual well being	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant
Time of participation	Citizen participation	All stages	Local community	Qualitative	Community	[127]	Construction or infrastructure development
Water pollution level	Safe and healthy living conditions	Transformation	Local community	Qualitative	Sector	[38]	Italian wine sector
Water pollution levels	Safe and healthy living conditions	Agriculture	Local community	Qualitative	Sector	[38]	Italian wine sector
Wine quality certification	Area reputation	Access to market	Local community	Qualitative	Sector	[38]	Italian wine sector
Working on this project provides	Physical wellbeing	All stages	Local community	Semi-quantitative	Company	[135]	Infant food production plant

recreation opportunity to the community							
Yes/no: Does the company have and enact policies that show respect for local culture including observance of cultural events?	Cultural heritage	All stages	Local Community	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Does the local community still retain access to raw materials extracted at a site or have access to the final product (electricity) generated at a site?	Access to material resources	All stages	Local Community	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Is company information available in all local languages?	Transparency	All stages	Local Community	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Is company information easily accessible for local community members?	Transparency	All stages	Local Community	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Is the percentage of the local community that is displaced different by	Equality	All stages	Local Community	Semi-quantitative	Region	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

population group in the area?							
Change in population size	Other	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
15–19 years old heavy episodic drinkers (population) (% by country) (Risk behavior)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Access to electricity (% of population)	Economic Status	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Adolescent fertility rate (per 1000 girls aged 15–19 years) (Risk behavior)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Anti-competitive risk	Fair competition	All stages	Local community, society	Quantitative	Company	[150]	Indian steel sector industry
Availability of resources for people with mental health issues	Services	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts

Change in access to financial resources	Income	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in access to information	Equality	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in access to necessary infrastructure	Services	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in affordable housing availability	Housing	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in availability of health resources	Health	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in availability of nutritious food	Health	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts

Change in crime rates	Public Safety	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in disease rates	Health	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in drug rate	Health	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in eating disorder rate	Health	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in educational program enrollment rate by gender	Education	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in high school graduation rate,	Education	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts

Change in life expectancy	Health	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in literacy rate	Education	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in number of people with health insurance	Health	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in number served by homeless shelters	Services	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Change in quality of life	Health	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Children do not attend school	Community and infrastructure	All stages	Local community, society	Quantitative	Country	[160]	Hydrogen energy production (electricity plant)
Commerce reports. Qualitative assessment turned into semi-	Technology development	All stages	Local community, society	Qualitative, semi-quantitative	Region, country, company	[136]	Vehicular fuels

quantitative. Payments for uses of patents.							
Commitment to the community	Commitment to the community	Production, processing, end of life	Local community, society	Na	Region, country	[113]	Multiple
Complaints by communities	Community engagement	All stages	Local community, society	Quantitative	Sector, company	[150]	Indian steel sector industry
Corruption	Corruption	Production, processing, end of life	Local community, society	Na	Region, country	[113]	Multiple
CSR reports, examples, storytelling. Qualitative assessment turned into semi-quantitative.	Public comments to sustainability issues	All stages	Local community, society	Semi-quantitative, quantitative	Company	[136]	Vehicular fuels
Diphtheria tetanus toxoid and pertussis (DTP3) immunization coverage among one-year-olds (%) (Immunization coverage)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Disposal strategies	Ecological impact	End of life	Local community, society	Quantitative	Product	[46]	Mobile phone

DMFT (decayed, missing or filled teeth) among 12-year-olds (Oral health)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Ecological impact E formula	Ecological impact	All stages	Local community, society	Quantitative	Product	[46]	Mobile phone
Education index	Education	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Electricity	Access to resources	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Electricity	Access to resources	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
EN1 Energy consumption	Environmental aspects	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EN2 Water consumption	Environmental aspects	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China

EN3 CO2 emissions	Environmental aspects	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EN4 SO2 emissions	Environmental aspects	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EN5 NOx emissions	Environmental aspects	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
En6 wastewater	Environmental aspects	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in china
EN7 Solid waste	Environmental aspects	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
EN8 Investments in environmental protection	Environmental aspects	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
Fragility of the legal system	Governance	All stages	Local community, society	Semi-quantitative, quantitative	Country	[160]	Hydrogen energy production (electricity plant)
Funds generated for charitable giving	Other	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal

							relationships between indicators and impacts
Government expenditure on education (% of GDP)	Education	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Gross enrolment ratio, pre-primary, both sexes (%)	Education	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Gross enrolment ratio, pre-primary, gender parity index (GPI)	Education	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Gross enrolment ratio, primary, both sexes (%)	Education	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Gross enrolment ratio, primary, gender parity index (GPI)	Education	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Gross enrolment ratio, secondary, both sexes (%)	Education	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Gross enrolment ratio, secondary, gender parity index (GPI)	Education	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level

Gross enrolment ratio, tertiary, gender parity index (GPI)	Education	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Health expenditure, public (% of total health expenditure) (Health expenditure)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Health index	Safe living conditions	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Health index	Safe & healthy living conditions	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Incidents of corruption	Corruption	All stages	Local community, society	Quantitative	Sector, company	[150]	Indian steel sector industry
Income index	Economic development contribution	All stages	Local community, society	Quantitative	Sector, company	[150]	Indian steel sector industry
Income index	Economic development contribution	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry

Income inequalities (GINI coefficient)	Equality	All stages	Local community, society	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies
Indigenous population	Human rights	All stages	Local community, society	Quantitative	Country	[160]	Hydrogen energy production (electricity plant)
Infant mortality rate	Healthcare	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Infrastructure	Access to resources	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Infrastructure	Access to resources	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Intentional homicide count and rate per 100,000 population	Safety	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Local job creation	Local job creation	Production, processing, end of life	Local community, society	Na	Region, country, company	[113]	Multiple
Long-term control functions	Participation and Influence	All stages	Local community, society	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies

Mortality from communicable disease	Health and safety	All stages	Local community, society	Semi-quantitative	Country	[160]	Hydrogen energy production (electricity plant)
Mortality rate	Healthcare	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Mortality rate attributed to household and ambient air pollution (per 100,000 population) (Hazardous pollutant)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Number of beneficiaries of a new product or service	Services	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Number of human rights violations	Equality	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Number of new incomes generating activities created	Income	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts

Number of new jobs created	Jobs	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Overall risk of corruption	Governance	All stages	Local community, society	Semi-quantitative, quantitative	Country	[160]	Hydrogen energy production (electricity plant)
Percentage of infants born with low birth weight (<2500 g) (Nutrition)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
PM2.5 air pollution, population exposed to levels exceeding World Health Organization (WHO) guideline value (% of total) Hazardous pollutant	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Possibility of misuse	Safety, security and tranquility	All stages	Local community, society	Qualitative	Region, country	[142]	Social impact assessment of prospective technologies
Potential action linked to the supply chain actors that have had positive impact on conflicts. Qualitative assessment turned into semi-quantitative.	Prevention and mitigation of armed conflicts	All stages	Local community, society	Semi-quantitative	Company	[136]	Vehicular fuels

Poverty index	Income	All stages	Local community, society	Quantitative	Region, country	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Public commitment to sustainability issues	Public commitment to sustainability issues	Production, processing, end of life	Local community, society	Na	Region, country	[113]	Multiple
Public debt (% of GDP)	Economic Status	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Regional inequalities (€)	Equality	All stages	Local community, society	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies
Renewable energy consumption (% of total final energy consumption)	Environmental aspects	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Risk of gender inequality	Human rights	All stages	Local community, society	Semi-quantitative	Country	[160]	Hydrogen energy production (electricity plant)
Risk of low life expectancy	Health and safety	All stages	Local community, society	Semi-quantitative	Country	[160]	Hydrogen energy production (electricity plant)

Risk perception	Safety, security and tranquility	All stages	Local community, society	Semi-quantitative	Region, country	[142]	Social impact assessment of prospective technologies
Risk too few hospital beds	Community and infrastructure	All stages	Local community, society	Semi-quantitative	Country	[160]	Hydrogen energy production (electricity plant)
S6 Profit and tax	Social Indicators	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
S7 Charitable contributions	Social Indicators	All stages	Local community, society	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
Sex ratio at birth (ratio)	Economic Status	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Share of national GDP/changes overtime in national GDP for the specific sector.	Economic development contribution	All stages	Local community, society	Quantitative	Country	[136]	Vehicular fuels
Spending on cultural activities	Cultural and sports	All stages	Local community, society	Quantitative	Sector, company	[150]	Indian steel sector industry

Spending on sports amenities	Cultural and sports	All stages	Local community, society	Quantitative	Sector, company	[150]	Indian steel sector industry
Stakeholder involvement	Participation and Influence	All stages	Local community, society	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies
Suicide rate (per 100,000 aged 15–29 years) (Mental health)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Sustainability/environ mental reporting	Transparency	All stages	Local community, society	Quantitative	Company	[150]	Indian steel sector industry
The extent of activities. Qualitative assessment turned into semi-quantitative.	Promoting social responsibility	All stages	Local community, society	Semi-quantitative	Company	[136]	Vehicular fuels
Trust in risk information	Participation and Influence	All stages	Local community, society	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies
Under-five mortality rate (probability of dying by age five per 1000 live births) (Child mortality)	Health	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level

Water availability	Access to resources	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Water availability	Access to resources	All stages	Local community, society	Quantitative	Region, country	[150]	Indian steel sector industry
Water depletion index (WDI) (ratio)	Environmental aspects	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Water facilities	Access to resources	All stages	Local community, society	Quantitative	Country	[150]	Indian steel sector industry
Water facilities	Access to resources	All stages	Local community, society	Quantitative	Region, country	[150]	Indian steel sector industry
Youth unemployment rate (% of total labor force ages 15–24)	Economic Status	All stages	Local community, society	Quantitative	Country	[182]	Sustainability Children Development Index at country level
Education index	Education	All stages	Local community, society, workers	Quantitative	Country	[150]	Indian steel sector industry
Knowledge-intensive jobs (h)	Safety, security and tranquility	All stages	Local community, society, workers	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies

Local employment created	Employment	All stages	Local community, society, workers	Quantitative	Sector, company	[150]	Indian steel sector industry
Support to local suppliers	Supplier relationships	All stages	Local community, society, workers	Quantitative	Country	[150]	Indian steel sector industry
Total employment (h)	Safety, security and tranquility	All stages	Local community, society, workers	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies
Employment	Economic impact	All stages	Local community, worker	Quantitative	Economic sector	[155]	Medical devices
Manufacturing process	Ecological impact	Processing	Local community, worker	Quantitative	Product	[46]	Mobile phone
Material consumption	Ecological impact	Production	Local community, worker	Quantitative	Product	[46]	Mobile phone
Resource consumption	Ecological impact	Production	Local community, worker	Quantitative	Product	[46]	Mobile phone
Change in gender wage gap	Equality	All stages	Local community, worker, society	Quantitative	Region, country, company	[49]	Evaluate company corporate practices; establish causal

							relationships between indicators and impacts
Intergenerational equity: a fair assessment of the risks that would entail current locations for future generations;	Equality, equal opportunities	All stages	Local community, worker, society	Semi-quantitative, quantitative	Country, community	[49]	Equity in the energy landscape
Procedural equity: location decisions and the same decision-making process are perceived as legitimate by all concerned communities;	Equality, equal opportunities	All stages	Local community, worker, society	Semi-quantitative, quantitative	Country, community	[49]	Equity in the energy landscape
Social equity: a fair distribution of costs and risks throughout society;	Equality, equal opportunities	All stages	Local community, worker, society	Semi-quantitative, quantitative	Country, community	[49]	Equity in the energy landscape
Spatial equity: a fair distribution of risks and costs throughout the territory;	Equality, equal opportunities	All stages	Local community, worker, society	Semi-quantitative, quantitative	Country, community	[49]	Equity in the energy landscape
Structural equity: when the localization process involves all aspects and interests.	Equality, equal opportunities	All stages	Local community, worker, society	Semi-quantitative, quantitative	Country, community	[49]	Equity in the energy landscape

Barometer of Sustainability	Ecosystem and social	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in China
Business sustainability indicators	Economic, environmental, social and institutional	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Composite sustainable development index	Economic, environmental and social	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Dow jones sustainability index	Economic, environmental and social	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Ecological footprint	Economic and environmental	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Energy sustainability index	Economics, technological	Reference sustainability indicators from	Reference sustainability indicators from	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china

	and environmental	other studies and articles	other studies and articles				
Energy technology sustainability index	Technical, economic, social, environmental and institutional	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Environmental sustainability index	Environmental health and ecosystem vitality	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Ford product sustainability index	Environmental & health, social and economic	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
General motors metrics	Environmental impact, energy consumption, personal health, occupational safety, manufacturing cost and waste management	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Global reporting initiative	Economic, environmental and social	Reference sustainability indicators from	Reference sustainability indicators from	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china

		other studies and articles	other studies and articles				
OECD sustainable manufacturing toolkit	Inputs related, operations related and products related	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Sustainability Indicators at EPA	Economic, environmental and social	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in China
Sustainability Indicators for Mining and Minerals Industry Environmental Sustainability Index	Economic, environmental and social	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in China
Triple bottom line sustainability indicators framework	Socioeconomic and environmental	Reference sustainability indicators from other studies and articles	Reference sustainability indicators from other studies and articles	Quantitative	Country	[157]	Internal combustion engine manufacturing company in china
Access to basic knowledge	Competence	Extraction	Society	Quantitative	Country	[44]	Aerospace industry
Access to info and communications	Competence	Extraction	Society	Quantitative	Country	[44]	Aerospace industry

Accessibility	Social growth	All stages	Society	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Business expansion	Economic impact	All stages	Society	Quantitative	Economic sector	[155]	Medical devices
Contribution of the system to economic development	Contribution to economic development	All stages	Society	Quantitative	Company	[192]	Packaging waste collection systems
Corruption	Impartiality	Extraction	Society	Quantitative	Country	[44]	Aerospace industry
Development technologies for sustainable management of oenological waste	Technology development	Transformation	Society	Qualitative	Sector	[38]	Italian wine sector
Development of technologies for water saving	Technology development	Transformation	Society	Qualitative	Sector	[38]	Italian wine sector
EBI (economic breeding index)	Technology development	Production, processing	Society	Semi-quantitative	Farm (company)	[151]	Irish Dairy Farm
Education and responsibility (Existence of educational campaigns	Public commitment on sustainability issues	Usage	Society	Semi-quantitative	Sector	[38]	Italian wine sector

for citizens engagement)							
Energy security (Percentage of domestic/locally sourced fuel)	Social acceptance and societal impacts	All stages	Society	Quantitative	Country	[137]	Bioenergy industry
Engaged government	Social justice	All stages	Society	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Estimated employment impact	Contribution to economic development	Agriculture	Society	Quantitative	Sector	[38]	Italian wine sector
Estimated evasion of social security contribution payments	Contribution to economic development	Agriculture	Society	Quantitative	Sector	[38]	Italian wine sector
Expenditure of National Health Service for basic and specialist medical visits, admission to hospital to cure injuries or diseases caused by a not responsible alcohol consumption.	Impact on national economy	Usage	Society	Quantitative	Sector	[38]	Italian wine sector
Extreme Poverty (derived from World	Forced labour	Production	Society	Quantitative	Country	[129]	Garment product chains

Bank absolute poverty line)							
Freedom of Speech	Influence	Extraction	Society	Quantitative	Country	[44]	Aerospace industry
Gender equity	Impartiality	Extraction	Society	Quantitative	Country	[44]	Aerospace industry
Growth in market share	Economic impact	All stages	Society	Quantitative	Economic sector	[155]	Medical devices
Health expenditure	Health and safety	Production, processing	Society	Quantitative (functional-unit related)	Country	[162]	Green concrete assessment in 6 countries
Human skills	Social justice	All stages	Society	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Increase of milk output to 2020 growth target	Contribution to economic	Production, processing	Society	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Legal system	Impartiality	Extraction	Society	Quantitative	Country	[44]	Aerospace industry
Local community engagement (Type and volume of engagement)	Social acceptance and societal impacts	All stages	Society	Quantitative	Country	[137]	Bioenergy industry

No. Of globally ranked universities	Competence	Extraction	Society	Quantitative	Country	[44]	Aerospace industry
Partnership with Universities	Technology development	Agriculture	Society	Qualitative	Sector	[38]	Italian wine sector
Partnership with Universities	Technology development	Transformation	Society	Qualitative	Sector	[38]	Italian wine sector
Public opinion (Percentage of public approval)	Social acceptance and societal impacts	All stages	Society	Quantitative	Country	[137]	Bioenergy industry
Public spending on education	Contribution to economic development	Production, processing	Society	Quantitative	Country	[162]	Green concrete assessment in 6 countries
R&D investments	Technology development	Agriculture	Society	Quantitative	Sector	[38]	Italian wine sector
R&D investments	Technology development	Transformation	Society	Quantitative	Sector	[38]	Italian wine sector
Regional (or national) rural area development projects	Technology development	Agriculture	Society	Quantitative	Sector	[38]	Italian wine sector
Risk of child labour	Human rights	All stages	Society	Semi-quantitative	Country	[160]	Hydrogen energy production (electricity plant)

Scale: What is the extent to which the activities along the life cycle of the electrical energy system have contributed to economic progress for different geographic regions or nations?	Contribution to economic development	All stages	Society	Semi-quantitative	Region, country	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Social capital and network	Social growth	All stages	Society	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Social cohesion and adhesion	Social growth	All stages	Society	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Social justice	Social justice	All stages	Society	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Years of tertiary schooling	Competence	Extraction	Society	Quantitative	Country	[44]	Aerospace industry
Yes/no: Are research and development results disseminated without barriers or monetary charges?	Technology development	All stages	Society	Semi-quantitative	Region, country	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

Yes/no: Are the companies and actors involved connected to violent conflicts, including war?	Prevention and mitigation of armed conflicts	All stages	Society	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Are the companies involved promoting the use of low-carbon energy systems over conventional fossil energy systems at their respective stages in the life cycle?	Public commitment on sustainability issues	All stages	Society	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Have the companies and actors been sued or fined for, or known to be involved in corruption and unethical practices?	Corruption	All stages	Society	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Is the technology used accessible and affordable to developing countries?	Technology development	All stages	Society	Semi-quantitative	Country	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Company/sectoral level green scheme	Promoting social responsibility	Production, processing	Value chain actor	Semi-quantitative	Farm (company)	[151]	Irish Dairy Farm

Establishment of a Code of conduct to prevent engaging in or being complicit in anticompetitive behavior	Fair competition	Agriculture	Value chain actor	Semi-quantitative	Sector	[38]	Italian wine sector
MSA (milk supply agreement) among dairy farmers	Supplier relationship	Production, processing	Value chain actor	Semi-quantitative	Farm (company)	[151]	Irish Dairy Farm
Payment on time	Supplier relationships	Agriculture	Value chain actor	Semi-quantitative	Sector	[38]	Italian wine sector
Public sector corruption	Corruption	Production, processing	Value chain actor	Quantitative (functional-unit related)	Country	[162]	Green concrete assessment in 6 countries
Request of implementing Environmental Management System	Promoting CSR	Agriculture	Value chain actor	Semi-quantitative	Sector	[38]	Italian wine sector
Request of possession of environmental and/or social certification.	Promoting CSR	Agriculture	Value chain actor	Semi-quantitative	Sector	[38]	Italian wine sector
Lost time injury frequency rate (LTIFR)	Health and safety Discrimination	All stages	Workers	Quantitative	Company	[150]	Indian steel sector industry

Profit-sharing and bonuses	Adequate Remuneration	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector, company	[124]	German wood-based bioeconomy
Rate of foreign employees a	Equal opportunities	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Working on this project kept me up-to-date on current events and facilitated my participation in activities that arouse my mind	Intellectual wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
% Of actions made with public funds related to waste management	Public comments to sustainability issues (governance)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
% Of citizens with access to reliable water management system	Customer/citizen participation (community satisfaction and participation)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems

% Of employment without a labor contract	Labor right	Production, processing and transportation/ distribution	Workers	Quantitative	Company	[131]	Biofuel aviation industry in brazil (three different fuel sources)
% Of formal workers from informal sector	Local labour integration of formal workers from informal sector (local development (socio-economic repercussion)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
% Of illegal workers	Working conditions	Agriculture	Workers	Quantitative	Sector	[38]	Italian wine sector
% Of users receiving environmental information on waste management	Development of environmental awareness and responsibility (local development (socio-economic repercussion)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
% Of vaccinated workers	Long-term health (health and safety)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
% Of workers at or above 18 and below 21	Child labour	Production, processing	Workers	Quantitative	Company	[31]	Bicycle frame

years of age exposed to physical harm							
% Of workers at or below 18 years of age	Child labour	Production, processing	Workers	Quantitative	Company	[31]	Bicycle frame
% Of workers who use personal protective equipment	Security and safety of workers (health and safety)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
% Of workers with information on the rights that correspond to the waste collector occupational code	Legal employments with social benefits and security (working benefits)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
% Of workers with no health problems	Long-term health (health and safety)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
% Of workers with no possibility of working in another sector	Workers from marginal classes (equal opportunities/dis crimination)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
% of workers with the possibility of paying the National Health Service	Workers and relatives with health insurance	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems

	(WORKING BENEFITS)						
Access to flexible working time agreements	Adequate Working Time	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector	[124]	German wood-based bioeconomy
Access to legal social benefits stipulated by law or sectoral agreements (sickness benefits, dental coverage etc.)	Social benefit	Agriculture	Workers	Semi-quantitative	Sector	[38]	Italian wine sector
Accessibility to the farm spaces	Society, culture and ecology	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Accidents	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Agreement on overtime payment and pay	Working Hours	Production, processing	Workers	Quantitative	Company	[31]	Bicycle frame
Annual employee retention rate (breakdown by age group, gender, socio-economic class, etc.)	Employee affiliation needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies

Annual percentage of employees receiving company-sponsored training for professional development (e.g., education reimbursement, cross-training opportunities, professional development seminars)	Employee actualization needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Appropriate working equipment	Health and safety	Agriculture	Workers	Qualitative	Sector	[38]	Italian wine sector
Associations and social implications	Ethical and human development	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Average wage of workers	Wage	Production, processing and transportation/ distribution	Workers	Quantitative	Company	[199]	Sugarcane industry
Bonded labour	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Capital participation	Adequate Remuneration	Production, processing, end of life and	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy

		transportation/ distribution					
Changes in DALY (or QALY) that can be linked to activities in the supply chain.	Safe and healthy living conditions	All stages	Workers	Semi-quantitative, quantitative	Company	[136]	Vehicular fuels
Child labour	Health	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry
Child labour	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Child labour	Child labour	Production, processing, end of life	Workers	Na	Company	[113]	Multiple
Child Labour (forced labour, not able to attend school)	Child labour	Production	Workers	Quantitative	Country	[129]	Garment product chains
Child labour (h)	Autonomy	All stages	Workers	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies
Child labour risk	Child labour	All stages	Workers	Quantitative	Sector, company	[150]	Indian steel sector industry
Collective bargaining agreements	Social sustainability	Multiple, as the indicators also	Workers	Quantitative	Company	[198]	Green supply chain

		cover company conduct					
Compensation for overtime	Adequate Working Time	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector	[124]	German wood-based bioeconomy
Contractual working hours	Adequate Working Time	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector, company	[124]	German wood-based bioeconomy
Cooperation	Ethical and human development	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Cooperation in labor-employer relations	Freedom of association and collective bargaining	Production, processing	Workers	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Cooperative education program workers (C7)	Child labour	Production, processing	Workers	Semi-quantitative	Company	[130]	Electronics industry
Cost of injuries	Safety and security	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[200]	Us advanced manufacturing cluster

Customer environmental awareness	Development of environmental awareness and responsibility (local development (socio-economic repercussion)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Customer knowledge about the system	Transparency corruption (value chain actor relationships)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Difference between average sectoral wage and national minimum wage	Fair wage	Production, processing	Workers	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Disabled employees	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Disabling injury frequency rate (C16) [(number of cases of disabling injury / total hours worked) × 1,000,000]	Health and safety	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry

Disabling injury severity rate (C17) [(total number of lost workdays / total hours worked) × 1,000,000]	Health and safety	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry
Discrimination	Discrimination	Production, processing, end of life	Workers	Na	Company	[113]	Multiple
Discrimination	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Discrimination on wage	Discrimination	All stages	Workers	Quantitative	Company	[150]	Indian steel sector industry
Distribution of responsibilities among family members	Equal opportunities	Agriculture	Workers	Qualitative	Sector	[38]	Italian wine sector
EC12 All-personnel labor productivity	Economic	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
Economic costs formula	Economic impact	Production, processing	Workers	Quantitative	Product	[46]	Mobile phone
Education	Society, culture and ecology	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms

Education and training	Social development	Production, processing, end of life	Workers	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Education and training	Learning and growth	All stages	Workers	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Education level	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Employee benefits	Employee benefits	Production, processing, end of life	Workers	NA	Company	[113]	Multiple
Employee complaints	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Employee layoffs	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Employee satisfaction	Social-human	Production, processing	Workers	Quantitative	Company	[16]	Manufacturing

Employees receiving minimum wages	Remuneration	All stages	Workers	Quantitative	Sector, company	[150]	Indian steel sector industry
Employees should receive and have access to written copies of their contracts	Working condition transparency	Production, processing	Workers	Semi-quantitative	Farm (company)	[151]	Irish Dairy Farm
Employment	Learning and growth	All stages	Workers	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Employment turnover	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Enforcement on the use of safety gear	Health and Safety	Production, processing	Workers	Quantitative	Company	[31]	Bicycle frame
Equal opportunities	Social development	Production, processing, end of life	Workers	Semi-quantitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Ergonomic load	Social impact	Production, processing	Workers	Quantitative	Product	[46]	Mobile phone

Evidence for restrictions to the freedom of association and collective bargaining	Freedom of association and collective bargaining (working rights)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Excessive working time	Labor rights	All stages	Workers	Quantitative	Company	[160]	Hydrogen energy production (electricity plant)
Existence of legal working contracts	Social benefits	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Fair practices	Safety and security	Production, processing, end of life	Workers	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Fatality rate/ECM	Health and safety	Production, processing	Workers	Quantitative (functional-unit related)	Farm (company)	[151]	Irish Dairy Farm
Female employees in management positions	Equal opportunities	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector, company	[124]	German wood-based bioeconomy
Forced labour	Health	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry

Forced labour	Forced labour	Production, processing, end of life	Workers	Na	Company	[113]	Multiple
Forced labour (h)	Autonomy	All stages	Workers	Quantitative	Region, country	[142]	Social impact assessment of prospective technologies
Forced labour risk	Forced labour	All stages	Workers	Quantitative	Sector, company	[150]	Indian steel sector industry
Fraction of female employees	Gender equity	Production, processing and transportation/ distribution	Workers	Quantitative	Company	[131]	Biofuel aviation industry in brazil (three different fuel sources)
Freedom of Association, Collective Bargaining and Right to Strike	Influence	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry
Freedom to form/join union	Freedom of Association	Production, processing	Workers	Quantitative	Company	[31]	Bicycle frame
Fulfilment of agreed contracts	Working conditions	Agriculture	Workers	Semi-quantitative	Sector	[38]	Italian wine sector
Full and part time employees	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain

GDP contribution	Social contribution	Production, processing and transportation/ distribution	Workers	Quantitative	Company	[131]	Biofuel aviation industry in Brazil (three different fuel sources)
Gender pay gaps	Gender discrimination (equal opportunities/dis crimination)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
Goods produced by the forced labor Trafficking in persons	Forced labour	Production, processing	Workers	Quantitative (functional-unit related)	Country	[162]	Green concrete assessment in 6 countries
Health and safety	Social-human	Production, processing	Workers	Quantitative	Company	[16]	Manufacturing
Health and safety	Social development	Production, processing, end of life	Workers	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Health and safety	Safety and security	Production, processing, end of life	Workers	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Health and safety	Health and safety	Production, processing, end of life	Workers	Na	Company	[113]	Multiple

Health Hazard from Emissions (Human Toxicity Level indicator In life-cycle assessment)	Individual wellbeing and social capital	All stages	Workers	Quantitative	Company	[137]	Bioenergy industry
Healthcare security coverage	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Hiring and firing practices	Social benefit and security	Production, processing	Workers	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Hours of health and safety training	Health	Production, processing	Workers	Quantitative	Company	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Hours per employee per day	Working Hours	Production, processing	Workers	Quantitative	Company	[31]	Bicycle frame
If the weekly working hours comply with legal arrangements or not	Working hours	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Implementation of risk control	Social sustainability	Multiple, as the indicators also	Workers	Quantitative	Company	[198]	Green supply chain

		cover company conduct					
Income distribution	Economic Impact	All stages	Workers	Quantitative	Region	[155]	Medical devices
Income Distribution	Social Sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Innovations	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Job exposure score	Social-human	Processing	Workers	Quantitative	Product	[16]	Manufacturing
Job security	Learning and growth	All stages	Workers	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Jobs generated	Employment	Production, processing and transportation/ distribution	Workers	Quantitative	Company	[131]	Biofuel aviation industry in brazil (three different fuel sources)

Labor practices	Safety and security	Production, processing, end of life	Workers	Quantitative, semi-quantitative, qualitative	Company	[196]	Business and corporation applications for decision making at the management level.
Labor union presence	Freedom of association and collective bargaining (working rights)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Landscape and territory	Quality of the products on the region	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Legislation on waste management	Maturity / existence of the informal waste management regulation (governance)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Level of education of workers families	Level of education of workers and their children (socio-economic conditions)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Lifestyle of Health and Sustainability (LOHAS) workplace (C19)	Health and safety	Production, processing	Workers	Semi-quantitative	Company	[130]	Electronics industry

Livestock management	Ethical and human development	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Living wage per month Minimum wage per month Sector average wage per months	Fair salary	Production, processing	Workers	Quantitative (functional-unit related)	Country	[162]	Green concrete assessment in 6 countries
Management of overtime hours (C13)	Working hours	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry
Manufacturing cost	Economic Impact	Processing	Workers	Quantitative	Product	[46]	Mobile phone
Material cost function	Economic impact	Processing	Workers	Quantitative	Product	[46]	Mobile phone
Measures to improve gender equality	Equal opportunities	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector, company	[124]	German wood-based bioeconomy
Measures to support older employees	Equal opportunities	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector, company	[124]	German wood-based bioeconomy
Migrant workers	Impartiality	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry

Migrant workers treated unfairly	Labor rights	All stages	Workers	Semi-quantitative	Company	[160]	Hydrogen energy production (electricity plant)
Minimum Acceptable Wage (based on minimum wages in rich countries and statistics on economic migrants)	Working conditions	Production	Workers	Quantitative	Country	[129]	Garment product chains
Minimum and fair wages for worker (C9)	Fair salary (S4)	Production, processing	Workers	Semi-quantitative	Company	[130]	Electronics industry
Minimum income according to law	Fair salary	Agriculture	Workers	Semi-quantitative	Sector	[38]	Italian wine sector
New products	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
No adequate labor laws	Labor rights	All stages	Workers	Semi-quantitative	Country	[160]	Hydrogen energy production (electricity plant)
No salary discrimination among female and male workers or among Italian and foreign workers	Equal opportunities	Agriculture	Workers	Qualitative	Sector	[38]	Italian wine sector

No salary discrimination among female and male workers, Italian and foreign workers Proportion of women employed	Equal opportunities	Transformation	Workers	Qualitative	Sector	[38]	Italian wine sector
Number of children working in the analyzed sector	Child/senior labour (human rights)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
Number of job-training and professional development programmes	Services	Production, processing	Workers	Quantitative	Company	[49]	Evaluate company corporate practices; establish causal relationships between indicators and impacts
Number of jobs created	Economic development contribution	Production, processing and transportation/ distribution	Workers	Quantitative	Company	[199]	Sugarcane industry
Number of occupational accidents	Health and safe working conditions	Production, processing and transportation/ distribution	Workers	Quantitative	Company	[199]	Sugarcane industry
Number of undocumented workers in waste management	Labour regulation (equal opportunities/discrimination)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems

Number of women working in waste management	Gender discrimination (equal opportunities/discrimination)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
Occupation Injuries and Deaths	Health	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry
Occupation Injuries and Hazards	Health	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry
Occupational accidents	Health & safety	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Occupational diseases	Health and safety	Agriculture	Workers	Quantitative	Sector	[38]	Italian wine sector
Occupational fatal accidents	Health & safety	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Occupational Health and Safety (Lost-time accidents among own employees per one million hours worked)	Individual wellbeing and social capital	All stages	Workers	Quantitative	Company	[137]	Bioenergy industry

Payment according to basic wage an Average remuneration level	Adequate Remuneration	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector, company	[124]	German wood-based bioeconomy
Per month average working hours (female) (C12)	Working hours	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry
Per month average working hours (male) (C11)	Working hours	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry
Percentage of employee health care costs provided by the company	Employee Safety/Security Needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees below the poverty line, adjusted for local cost of living	Employee Basic Needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees eligible for government assistance	Employee Basic Needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees that believe professional	Employee actualization needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies

development activities are helpful to them							
Percentage of employees that believe the company values their quality of life	Employee esteem needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees that believe their contribution to the company is valued	Employee esteem needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees that believe they are able to pursue their own professional interests on the job	Employee actualization needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees that believe they belong or feel a sense of connectedness within the company	Employee affiliation needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees that believe they have adequate time to attend to their basic	Employee Basic Needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies

Percentage of employees that believe they have experienced harassment due to their gender, gender identity, sexual orientation, race, religion, etc.	Employee Safety/Security Needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees that envision themselves at the company for the remainder of their career	Employee affiliation needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of employees that would recommend the company to a friend or relative as a place to work	Employee affiliation needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of labor that is child labor	Child labour	All stages	Workers	Semi-quantitative	Company, region, country	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Percentage of labor that is unpaid	Fair salary	All stages	Workers	Semi-quantitative	Company, region, country	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

Percentage of old labor (65+)	Old labor	Production, processing	Workers	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Percentage of positions that were filled by internal applicants, as opposed to outside hires	Employee actualization needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Percentage of workers answering "no" to a question "Are percentages of male/female workers are equal?	Free of discrimination	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering "no" to a question "Do all workers present on the field have access to drinking water in sufficient quantity?	Health and safety	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering "no" to a question "Do all workers present on the field have access to first aid and provision for emergency response?	Health and safety	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

Percentage of workers answering “no” to a question “Do male and female workers get the same wages for doing same task?	Free of discrimination	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “no” to a question “Do you have freedom of association and collective bargaining?	Freedom of association and collective bargaining Satisfaction of job	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “no” to a question “Do you receive at least the government regulated minimum wage (300B/day)?	Fair wages	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “no” to a question “Do you volunteer to work overtime and the overtime work is paid at premium rate?	Free of child labor	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “no” to a question “Does your employer supply	Health and safety	Production, processing, end of life and	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

appropriate personal protective equipment?		transportation/ distribution					
Percentage of workers answering “no” to a question “If the personal protective equipment is supplied, do you use it?”	Health and safety	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “no” to a question “Is the sugarcane farm you work in free of forced labor?	Free of forced labor	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Are you satisfied with your job?	Freedom of association and collective bargaining Satisfaction of job	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do workers received social benefits?	Social benefits	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this	Consumer privacy	Production, processing, end of life and	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

social subcategory (both positively and negatively)?		transportation/ distribution					
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Feedback mechanism	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Local employment	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Safe & healthy living conditions	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this	Respect of cultural heritage	Production, processing, end of life and	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

social subcategory (both positively and negatively)?		transportation/ distribution					
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Secure living conditions	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Public commitments to sustainability issues	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Technology development	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this	Fair competition	Production, processing, end of life and	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

social subcategory (both positively and negatively)?		transportation/ distribution					
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Supplier relationships	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Health & safety	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	End of life responsibility	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this	Transparency	Production, processing, end of life and	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

social subcategory (both positively and negatively)?		transportation/ distribution					
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Delocalization and migration	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Access to material resources	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Respect of indigenous rights	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this	Contribution to economic development	Production, processing, end of life and	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

social subcategory (both positively and negatively)?		transportation/ distribution					
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Free of corruption	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Prevention & mitigation of armed conflicts	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?	Promoting social responsibility	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this	Respect of intellectual property rights	Production, processing, end of life and	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

social subcategory (both positively and negatively)?		transportation/ distribution					
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?”B	Access to immaterial resources	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that the sugar industry contributes to this social subcategory (both positively and negatively)?”B	Community engagement	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Do you feel that you receive fair wage?”	Fair wages	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Does your maximum working hours exceed 60 h per week?	Fair working hours	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry

Percentage of workers answering “yes” to a question “Have you ever experienced legitimate land contest by other users?	Land rights	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Have you ever experienced legitimate water contest by other users?	Water rights	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers answering “yes” to a question “Is there any child labor in the sugarcane farm you work in?	Free of child labor	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Company	[144]	Thailand Sugar Industry
Percentage of workers earning a living wage based on their location	Fair salary	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Percentage of workers earning the legal minimum wage	Fair salary	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

Percentage of workers who are paid a living wage	Wage	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Percentage of workers with benefits such as health insurance	Social benefit and social security	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Percentage of young dairy labor (<35, not including child labor)	Young labor	Production, processing	Workers	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Personnel security training	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Physiological needs (e.g., eating, drinking, using the restroom) during work hours	Employee basic needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	Us companies
Potential occupational accidents	Working conditions	Production, processing and transportation/ distribution	Workers	Quantitative	Company	[131]	Biofuel aviation industry in brazil (three different fuel sources)
Poverty	Health	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry

Premium rate for the overtime	Fair salary	Agriculture	Workers	Quantitative	Sector	[38]	Italian wine sector
Presence of child labour	Child labour	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of forced labour	Forced labour	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of getting occupational health risk	Health and safe working conditions	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of health and safety awareness	Health and safe working conditions	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of incidents	Health and safe working conditions	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of periodical public company reports	Transparency corruption (value chain actor relationships)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems

Presence of political, regional and religious discrimination	Discrimination	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of protective equipment	Health and safe working conditions	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of safety risk of the system	Health and safe working conditions	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of social security	Social benefits	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of work satisfaction	Job satisfaction and engagement	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Presence of workers identified who are members of associations able to organize themselves and/or bargain collectively	Freedom of association and collective bargaining	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Preventing forced work practices (C8)	Forced labour	Production, processing	Workers	Semi-quantitative	Company	[130]	Electronics industry

Preventive health measures	Health & safety	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector, company	[124]	German wood-based bioeconomy
Professional development	Social-human	Production, processing	Workers	Quantitative	Company	[16]	Manufacturing
Promoting freedom of association (C4)	Freedom of association and collective bargaining	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry
Promotion rate	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Proportion of foreign illegal workers	Equal opportunities	Agriculture	Workers	Quantitative	Sector	[38]	Italian wine sector
Proportion of women employed	Equal opportunities	Agriculture	Workers	Quantitative	Sector	[38]	Italian wine sector
Proposed penalty case rate (C18) [(number of violation cases / total no. Of enterprises inspected) × 100]	Health and safety	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry

Protecting children from having to work (C6)	Child labour	Production, processing	Workers	Semi-quantitative	Company	[130]	Electronics industry
Protecting worker against discrimination during both the recruitment process and the term of your employment (C15)	Equal opportunities/ discrimination (S6)	Production, processing	Workers	Semi-quantitative	Company	[130]	Electronics industry
Provision of safety gear	Health and Safety	Production, processing	Workers	Quantitative	Company	[31]	Bicycle frame
Quality of the products	Quality of the products on the region	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Quality of workers/customers houses	Safe and healthy living conditions (access to material resources) (socio-economic conditions)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Quantification of the average and maximum numbers of hours worked per week by workers at different levels	Working hours	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

Quantification of the number of holidays and other paid time off available to workers annually	Fair salary	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Quantification of the number of workplace accidents resulting in injuries or death over a period of time	Health and safe working conditions	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Quantification of wage gaps by sex, gender, nationality, cultural group, and race	Equal opportunity and discrimination	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Rate of disability employment (C14) [(disability employments / paid employees) × 100]	Equal opportunities/ discrimination (S6)	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry
Rate of disabled employees	Equal opportunities	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Rate of dispatching workers (C3) [(number of part-time workers /	Freedom of association and collective bargaining	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry

numbers of paid employees) × 100]							
Rate of employees in research and development	Knowledge Capital	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Rate of employees participated in training	Knowledge Capital	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Rate of employees provided by temporary work agencies	Employment	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Rate of fixed-term employees	Employment	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Rate of labor dispute involvement (C1) [(number of workers involved in dispute / number of paid employees) × 1000]	Freedom of association and collective bargaining	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry

Rate of labor union organization (C2) [(number of trade union members / number of paid employees) × 100]	Freedom of association and collective bargaining	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry
Rate of marginally employees (max 450V)	Employment	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Rate of part-time employees	Adequate Working Time	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Rate of qualified employees	Employment	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Rate of vocational trainees	Knowledge Capital	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy

Ratio of average annual scheduled work hours not lost due to injury or illness per employee to average annual scheduled work hours per employee	Employee Safety/Security Needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Ratio of genders	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Ratio of lowest quintile for salary to highest quintile for salary	Employee esteem needs	Production, processing, end of life	Workers	Quantitative	Company	[140]	US companies
Regular payment	Wage	Production, processing, end of life	Workers	Semi-quantitative	Company	[192]	Packaging waste collection systems
Regular payment	Fair salary	Agriculture	Workers	Quantitative	Sector	[38]	Italian wine sector
Related activities	Short food supply chain and related activities	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Right to collective bargaining (C5)	Freedom of association and collective bargaining	Production, processing	Workers	Quantitative	Company	[130]	Electronics industry

Right to strike	Labor rights	All stages	Workers	Semi-quantitative	Company, country	[160]	Hydrogen energy production (electricity plant)
Rights of indigenous people	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Risk assessment	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Risk of average wage below minimum wage	Labor rights	All stages	Workers	Semi-quantitative	Company, country	[160]	Hydrogen energy production (electricity plant)
Risk of fatal injuries	Health and safety	All stages	Workers	Semi-quantitative	Company	[160]	Hydrogen energy production (electricity plant)
Risk of forced labour	Labor rights	All stages	Workers	Semi-quantitative	Company, country	[160]	Hydrogen energy production (electricity plant)
Risk of workplace noise	Labor rights	All stages	Workers	Semi-quantitative	Company	[160]	Hydrogen energy production (electricity plant)
Rural buildings	Quality of the products on the region	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms

S1 R&D personnel proportion of total employees S2 Ratio between female and male employees	Social Indicators	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
S3 Employee attrition rate	Social Indicators	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
S4 Employee training number	Social Indicators	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
S5 Safety accident frequency	Social Indicators	All stages	Workers	Quantitative	Company	[157]	Internal combustion engine manufacturing company in China
Scientific publications	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Security	Social development	Production, processing, end of life	Workers	Quantitative, semi-quantitative, qualitative	Country (social)	[196]	Business and corporation applications for decision making at the management level.
Share of additional benefits supplied in relation to a potential full package of social benefits offered	Social benefits	All stages	Workers	Semi-quantitative, quantitative	Company	[136]	Vehicular fuels

Share of additional capacity building supplied in relation to a full package, or share of employees benefit from capacity building activities	Capacity building	All stages	Workers	Semi-quantitative	Company	[136]	Vehicular fuels
Share of female dairy worker in total diary work force	Equal opportunity and discrimination	Production, processing	Workers	Quantitative (non-functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Short food supply chain	Short food supply chain and related activities	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Sick-leave days	Health & safety	Production, processing, end of life and transportation/ distribution	Workers	Quantitative	Sector	[124]	German wood-based bioeconomy
Skill development	Employment	All stages	Workers	Quantitative	Sector, company	[150]	Indian steel sector industry
Social benefits provided to workers (C10)	Fair salary (S4)	Production, processing	Workers	Semi-quantitative	Company	[130]	Electronics industry
Social welfare/ satisfaction (quality of product/service)	Customer/citize n satisfaction (community	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems

	satisfaction and participation)						
Static risk score	Social-human	Processing	Workers	Quantitative	Product	[16]	Manufacturing
Support for professional qualification	Knowledge Capital	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector	[124]	German wood-based bioeconomy
Sustainability of the employment	Work	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Sustainable suppliers' practice	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Sustainable use of materials	Society, culture and ecology	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
The level of exposure to injuries, harm and contagious disease while working on this project	Physical wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Time lost	Social sustainability	Multiple, as the indicators also	Workers	Quantitative	Company	[198]	Green supply chain

		cover company conduct					
Total monthly family income	Social characteristics of population (socio-economic conditions)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
Training	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Training	Work	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Training (Hours of training per employee per year)	Individual wellbeing and social capital	All stages	Workers	Quantitative	Company	[136]	Bioenergy industry
Training and professional development(university/company/institute)	Professional development	Production, processing	Workers	Semi-quantitative	Farm (company)	[151]	Irish Dairy Farm
Training courses	Professional Growth	Agriculture	Workers	Semi-quantitative	Sector	[38]	Italian wine sector
Unemployment	Labor rights	All stages	Workers	Quantitative	Country	[160]	Hydrogen energy production (electricity plant)

Unionized employees	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Use of safety gear	Health and Safety	Production, processing	Workers	Quantitative	Company	[31]	Bicycle frame
Vacation	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Wage assessment	Health	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry
Wage level between genders	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Wages under $2 a day	Labor rights	All stages	Workers	Quantitative	Company	[160]	Hydrogen energy production (electricity plant)
Waste management	Society, culture and ecology	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms
Weekly hours actually worked by employees	Weekly hours and/or weekly rest (quality of job	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems

	positions/working conditions)						
Weekly hours of work per employee	Working time	Production, processing	Workers	Quantitative (functional-unit related)	Country	[162]	Green concrete assessment in 6 countries
Weekly working hours	Weekly working hours	Production, processing, end of life	Workers	Na	Company	[113]	Multiple
While working on this project I experienced satisfaction/pleasure in my employment and gave me a positive attitude to work	Occupational/vocational wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Willingness to be trained regarding the work activities	Professional Growth	Agriculture	Workers	Qualitative	Sector	[38]	Italian wine sector
Willingness to continue fulfilling the same function	Professional Growth	Agriculture	Workers	Qualitative	Sector	[38]	Italian wine sector
Willingness to continue working in the same company or sector	Professional Growth	Agriculture	Workers	Qualitative	Sector	[38]	Italian wine sector
Work	Work	All stages	Workers	Quantitative	Farm	[139]	Rural wine farms

Work accidents, complaints for injuries	Health and safety	Agriculture	Workers	Quantitative	Sector	[38]	Italian wine sector
Work satisfaction	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Work-life balance (% of workers that can benefit from flexible working arrangements to balance work and private life)	Working conditions	Agriculture	Workers	Quantitative	Sector	[38]	Italian wine sector
Worker salary compared to minimum wage	Fair salary (quality of job positions/workin g conditions)	Production, processing, end of life	Workers	Quantitative	Company	[141]	Waste management collection systems
Worker wages	Worker wages	Production, processing, end of life	Workers	Quantitative	Company	[113]	Multiple
Workers environmental education and awareness	Degree of environmental worker awareness (professional development)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems

Workers have access to meetings and the possibility to dispute resolution procedures	Freedom of association and collective bargaining (working rights)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Workers level of education	Level of education of workers and their children (socio-economic conditions)	Production, processing, end of life	Workers	Qualitative	Company	[141]	Waste management collection systems
Working hours ratio	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Working on this project allowed me to freely express my feeling and share my views	Emotional wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project enabled me to learn time management skills	Emotional wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project encouraged creativity and	Intellectual wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant

stimulated my mental activities							
Working on this project encouraged me to conserve material, energy and water resources (i.e. Reduce, reuse, recycle) thereby minimizing harm to the environment	Environmental wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project encouraged me to cultivate optimistic attitude	Emotional wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project encouraged me to meditate regularly and foster my commitment to my beliefs	Spiritual well being	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project enhanced my vision for the future	Occupational/vocational wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project facilitated my openness to change and learn new skills	Occupational/vocational wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant

Working on this project gave me and those around me the freedom to be who we are	Spiritual well being	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project helped me learn good communication skills (of my thoughts, feelings and ideas)	Social well being	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project increased my awareness regarding effects of our daily habits on the physical environment	Environmental wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project made me develop healthy habits (i.e. Adequate rest, stop smoking, use safety equipment, etc.) .	Physical wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project made me see opportunities for growth in the challenges that life brings	Spiritual well being	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant

Working on this project propelled me to get involved, share my talents and skills, and contribute to my community	Social well being	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working on this project provides me opportunity to exercise my body	Physical wellbeing	All stages	Workers	Semi-quantitative	Company	[135]	Infant food production plant
Working time	Health	Extraction	Workers	Quantitative	Country	[44]	Aerospace industry
Working time (second)/ECM	Working hours	Production, processing	Workers	Quantitative (functional unit related)	Farm (company)	[151]	Irish Dairy Farm
Works council	Participation	Production, processing, end of life and transportation/ distribution	Workers	Qualitative	Sector, company	[124]	German wood-based bioeconomy
Years of service ratio	Social sustainability	Multiple, as the indicators also cover company conduct	Workers	Quantitative	Company	[198]	Green supply chain
Yes/no: Are appropriate safety education and training	Health and safe working conditions	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across

provided to employees?							populations of different socioeconomic backgrounds
Yes/no: Are employees paid at known and regular intervals?	Fair salary	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Are employees unionized?	Freedom of association and collective bargaining	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Are there deductions on employees' wages that were enacted for reasons beyond an employee's control?	Transparency	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Are workers free to end their employment and not tied by debt to a company, lack of mobility, monopoly of employment in the region by the company, or the company holding onto their legal documentation?	Forced labour	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds

Yes/no: Do workers have the right to unionize?	Freedom of association and collective bargaining	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
Yes/no: Is the appropriate safety equipment for workers' activities consistently available and accessible to employees?	Health and safe working conditions	All stages	Workers	Semi-quantitative	Company	[128]	Low carbon energy production; energy justice evaluation across populations of different socioeconomic backgrounds
End of life/modularity	Environmental Impact	End of life	Workers, local community, society	Quantitative	Product	[155]	Medical devices
Excessive Working Hours (forced labour, involuntary)	Forced labour	Production	Workers, local community, society	Quantitative	Country	[129]	Garment product chains
Local unemployment	Employment	All stages	Workers, local community, society	Quantitative	Region	[127]	Construction or infrastructure development
Maximum and minimum national unemployment	Employment	All stages	Workers, local community, society	Quantitative	Country	[127]	Construction or infrastructure development
Number of monthly contracts	Employment	All stages	Workers, local community, society	Quantitative	Company	[127]	Construction or infrastructure development

Occupational Safety and Health (based on statistics of ILO)	Health and safe working conditions	Production	Workers, local community, society	Quantitative	Country, community	[129]	Garment product chains
Safety during construction work	Safe environment	All stages	Workers, local community, society	Semi-quantitative	Company	[127]	Construction or infrastructure development
Safety for the operation of infrastructure	Safe environment	All stages	Workers, local community, society	Qualitative	Company	[127]	Construction or infrastructure development
Zonal insecurity conditions	Safe environment	All stages	Workers, local community, society	Qualitative	Community	[127]	Construction or infrastructure development

APPENDIX F SIMPLIFIED SIA FRAMEWORK

Social Impact Assessment (SIA) for Capstone Design

The procedure in this document will help you to plan and execute a Social Impact Assessment to give you a clearer picture of the effect your design might have on the world around it. The outline should familiarize you with the process of performing a Social Impact Assessment (SIA) of a design. Once you complete the steps in this outline, **you may use it to create the section on the social impact of your design for your final report for Capstone Design.**

The procedure consists of three steps: (I) Defining the Goal and Scope, (II) Performing an Inventory Analysis, and (III) Interpreting the Results.

An example is provided for a Social Impact Assessment of a laptop computer [1]. An Appendix of definitions is provided with this document.

I. Define the goal and scope

Defining the goal and scope of the study is the first step in the SIA as it provides context and its definition affects the subsequent steps of the analysis. The *goal* of the SIA describes the objective of the study, or basically the reasons for performing it. The s*cope* describes the design system being studied, the product lifecycle stages considered in the analysis and the definition of the functional unit. The goal and scope are captured in tabular form. Refer to Table F1 for an example of the output of the goal and scope step.

A. Define the objective of the study

- What do you hope to learn from your social impact assessment about your design/product?
    - Why is the analysis being performed?
- What stage in your design process are you in when this assessment is being performed?

B. Define the scope

- The scope defines: the function of the design being studied, the functional unit, the product lifecycle stages considered and its associated activities.
- Describe your design
    - What design problem or opportunity are you addressing?
    - What is the intended purpose or function of the design? (Should begin with action verb)
- If you're assessing more than one design alternative, describe each design alternative.

C. Define your functional unit

- The functional unit is a quantifiable element related to the product being studied, such as the product itself, a subcomponent of the product, etc.

D. **Select the lifecycle stages considered in this assessment of your design**

- Determine which stages of the design/product lifecycle(**shown in bold**) will you consider:
    - **Production**
        - Raw material extraction
        - Material Processing
    - **Manufacturing**
        - Material forming or molding
        - Product assembly
    - **Product use**
        - Customer use of product
        - Associated product maintenance
    - **End of Life**
        - Landfill disposal
        - Recycling/Reuse
        - Incineration

Summarize the results from the Goal and Scope step as shown in Table F1.

Table F1: Example Goal and Scope Section Summary

Objective of Study	Design Function	Functional Unit	Lifecycle Stages Considered	Associated Activities
Assess social impacts of laptop computer	Provide desktop computer functionalities in a lightweight and portable package	1 laptop computer	Production	Raw material extraction
			Processing	Assembly of components

II. Inventory Analysis

The inventory analysis determines the relevant stakeholder groups, social impact categories and the social impact indicators of the SIA analysis. The data is organized hierarchically by stakeholder group, social impact categories and social as shown in Figure

1. The output of the Inventory Analysis step is captured in tabular form. Refer to Table F4 for an example of the output of the inventory analysis step.

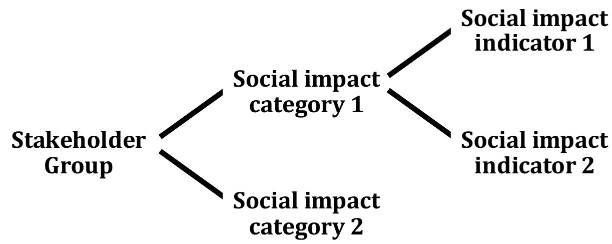

Figure F1: Hierarchy of analysis data based on the stakeholder groups

A. Select applicable stakeholder groups

- What are the stakeholder groups in your design context/problem?
  - A stakeholder group is defined as a group of individuals that share a set of characteristics on how they are affected by the product lifecycle activities
- Select among the 5 stakeholder groups shown in the first column of Table F2
  - The selection should be based on the goal and scope of your analysis and on the product lifecycle stages that you are considering for your social impact assessment.
- Are there additional groups that should be considered in your social impact assessment that aren't represented by the groups suggested in Table F2? If so, document them.

Table F2: Stakeholder groups with definitions and examples.

Stakeholder Group	Definition	Examples
Consumers	Individuals that interact with the product when using it	● Sugar consumers [2] ● Bamboo bicycle users [3] ● Laptop users [1] ● Vehicle users [6]
Local community	Individuals living near facilities where product lifecycle activities are conducted	● People living around sugar farms (not workers) [2] ● People living around bamboo bicycle frame production companies [3] ● People living near Copper mines [1]
Society	Refers to norms, rules, and laws regulating socioeconomic development. This group also refers to a collection of individuals at a bigger scale than	● Government representatives [2] ● Sustainability related policies [4] ● Mining company codes of conduct [1]

	the local community stakeholder group. [5]	
Value-chain actors	Individuals involved in activities to create the product, without having direct contact with it.	● Sugar farm owners [2] ● Bamboo farm owners [3] ● Extracted material distributors [1]
Workers	Individuals that directly act on the activities for producing the product	● Sugarcane farms employees [2] ● Bicycle frame companies workers [3] ● Copper mine extraction workers [1] ● Tire manufacturing employees [6]

B. Select applicable social impact categories

- Social impact categories are defined as logical groupings of social impact results related to the social issues of interest for each stakeholder group [5].
- Select among the social impact categories shown in Table F3, based on the goal and scope of the study and on the stakeholder groups selected in Step II-A.
- Refer to the 2011 UNEP Methodological Sheets [4] **(provided)** to see a full list of impact categories for each stakeholder group, as Table F3 only contains a few examples.

Table F3: Example social impact categories for consumer and local community stakeholder group.

Stakeholder Group	Social Impact Category	Definition
Consumer	Health and Safety	Customers expect the product that doesn't pose a risk to their health and safety when used.
	Feedback Mechanisms	Paths through which consumers can communicate their product satisfaction to a company.
	End-of-Life Responsibility	The extent that companies inform the consumer about the possible end-of-life options of the product.
Local community	Delocalization and Migration	The extent of organization's contribution to involuntary delocalization of populations due to lifecycle product processes.
	Local Employment	The effects of an organization in the local employment. This includes income and

		training opportunities to community members.
	Access to Material Resources	The extent to which organizations work to protect, provide, or improve community access to material resources and infrastructure.

C. **Select applicable impact indicators**

- Social impact indicators provide a measure of the social aspect being evaluated [5].
  Select corresponding indicators for each selected social impact category using the 2011 UNEP Methodological Sheets [4]. Summarize them as shown in Table F4 **(note that this appears as Table F2 in the fillable template document)**, for each lifecycle stage, stakeholder group, and social impact category you have selected.

Table F4: Example Inventory Analysis Section Summary

Product Lifecycle Stage	Stakeholder Group	Social Impact Category	Impact Indicators
Production	Workers	Child Labor	% of children working in country/sector
			Accident rate by country/sector
		Health and Safety	Extraction of material resources and level of industrial water use
	Local Community	Access to material resources	Number of hours worked per employee
Processing	Workers	Hours of Work	% of children working in country/sector

III. Interpreting the Results

- Based on the analysis performed in Steps I and II, write a reflection addressing the following questions:
  - How do you predict your design will impact human well-being, positively and negatively?
  - What steps can you take to minimize the negative social impacts of your design?

- In completing Steps I and II, what was your reasoning for the selection of the:
    - lifecycle stages?
    - stakeholder groups?
    - social impact categories and indicators?
- Your reflection should not be framed in a question-and-answer format.

Example Reflection for Social Impact Assessment of Laptop Computer

How do you predict your design will impact human well-being, positively and negatively?

Numerous potential positive social impacts are expected from the lifecycle activities. Laptop components are usually produced in countries with lower employee wages, so employment and job creation is an expected benefit. As with any computer, laptops are enabling technologies that allow users increasing capabilities, especially for professional purposes. Laptops are global products that promote trade and global economic prosperity due to the multinational actors involved from the design process to the creation of the tangible product.

Potential negative impacts are expected for the worker stakeholder group. Laptop component production and processing is usually performed in less developed countries due to their lower labor costs. Lower labor costs are usually associated with poor labor regulations that fail to protect employees relative to countries with more strict labor code practice and oversight. Laptop components require the extraction of rare earth metals that involve dangerous and polluting mining processes. In addition, these processes may also involve a significant use of natural resources, which is critical in countries with low employee wages.

What steps can you take to minimize the negative social impacts of your design?

Because there is significant concern for unregulated labor practices, it will be wise to select companies that are established in countries with labor regulations that protect workers and avoid any type of child labor. It will be advised to consider companies that promote and enforce the use of safety gear and practices among its employees and that provides regular safety training to their employees. Another important aspect to consider is to implement designs that have a reduced use of natural resources or even more importantly, to select companies and countries that have sustainable practices and agreements in place to protect the environment.

In completing Steps I and II, what was your reasoning for the selection of the:

- **lifecycle stages?**

The production and manufacturing lifecycle stages were selected because it was assumed that these two have the greatest potential for social impacts relative to the rest of the stages.

- **stakeholder groups?**

Based on the selected lifecycle stages, the workers and the local community are the stakeholder groups expected to have the greatest social impact.

- **social impact categories and indicators?**

The social impact indicators selected in the analysis for the worker stakeholder group are based on the history of poor labor laws and working conditions in the country where most of the production and processing activities occur (China).

Table F5: Definition of terms

Term	Definition
Consumer Stakeholder Group	Individuals that interact with the product during the use phase of the product lifecycle. [2]
Functional Unit	A functional unit is a measure of the performance of the functional outputs of the product. [201]
Local Community Stakeholder group	Individuals living near facilities where product lifecycle activities are conducted. [2]
Primary Data	Data that is specific for a company or product lifecycle activity collected directly from the source via interviews, questionnaires or surveys [6]
Performance Reference Points	Reference values that give an indication of the current state of a metric from a social context [134]. Performance Reference points may be internationally set thresholds, goals or objectives according to conventions and best practices [2].
Qualitative Indicator	Qualitative indicators are normative, meaning that they provide their descriptions using words. Qualitative indicators are important when measuring stakeholder perception about issues that are hard to quantify. One example is the perception of employees regarding the strength of a management system to protect consumer privacy
Quantitative Indicator	Quantitative indicators provide their description using numbers, like for example the number of accidents reported during a manufacturing process
Secondary Data	Data that is not collected directly from the source or product lifecycle activity being studied [6].

Social Impact Indicators	Social impact indicators are evidence, subjective or objective, qualitative, quantitative or semi-quantitative, being collected in order to facilitate concise, comprehensive and balanced judgments about the condition of specific social aspects with respect to a set of values and goals. Indicators are specific definitions of the data sought. [2,26]
Social Life Cycle Assessment (S-LCA)	S-LCA is a social impact assessment method that aims to assess the social and socio-economic aspects of products and their positive and negative impacts along their life cycle, encompassing extraction and processing of raw materials, manufacturing, distribution, use, re-use, maintenance, recycling, and final disposal. [2,26]
Society Stakeholder Group	Refers to norms, rules and laws regulating socioeconomic development. This group also refers to a collection of individuals at a bigger scale than the local community stakeholder group. [2]
Stakeholder	Any individual that has an interest in any activities or decisions of an organization. [2,12]
Stakeholder Categories/Groups	A cluster of stakeholders that are expected to have shared interest due to their similar relationship to the investigated product [2]; groups upon which the product has an impact along its lifecycle. [6]
Semi-Quantitative Indicator	Semi-quantitative indicators provide descriptions based on yes or no answers (binary) or using a scoring system such as a Likert scale. One example is the presence of a stress management program in a company
System Boundaries	A set of criteria specifying which unit processes are part of a product system considered in the social impact analysis. [2]
Value chain	The full range of activities that firms and workers to bring a product, from its conception to its end of life, including design, production, marketing, distribution and support.
Value-chain actor	Individuals involved in activities to create the product without having direct contact with the product. Every person that adds value to a product; an identifiable company, or well-organized community of small-scale entrepreneurs. [2,165]
Worker Stakeholder group	Individuals that directly acts on the activities for producing the product. [2]

APPENDIX G TEMPLATES TO ORGANIZE RESULTS

Social Impact Assessment (SIA) Results Template

This document provides a template to organize the results obtained by following the Social Impact Assessment (SIA) procedure. The template consists of three sections corresponding to the SIA steps in the "SIA Outline" document.: (I) Define the Goal and Scope, (II) Perform an Inventory Analysis, and (III) Interpret the Results. Follow the instructions presented in the SIA Outline document when completing the template.

I. Goal and Scope

Complete **Table G1** based on the SIA procedure.

Table G1: Goal and Scope Section Summary

Objective of Assessment	Design Function	Functional Unit	Lifecycle Stages Considered	Associated Activities

II. Inventory Analysis

Complete **Table G2** based on the SIA procedure. Use the provided 2011 United Nations Environmental Program Methodological Sheets to find applicable social impact categories and indicators.

Table G2: Inventory Analysis Section Summary

Product Lifecycle Stage	Stakeholder Group	Social Impact Category	Impact Indicators

III. Interpreting the Results

Write a reflection addressing the following questions (pay attention to the instructions in the SIA Outline document):

- How do you predict your design will impact human well-being, positively and negatively?
- What steps can you take to minimize the negative social impacts of your design?

In completing Steps I and II, what was your reasoning for the selection of the:

- lifecycle stages?
- stakeholder groups?
- Social impact categories and indicators?

APPENDIX H CAPSTONE FEEDBACK ELECTRONIC SURVEY

Q1 What is your name? [First Last]

Q2 How do you categorize yourself?

White/Caucasian (1)

Hispanic/Latino/a/x (2)

Black or African American (3)

Native American or American Indian (4)

Asian or Pacific Islander (5)

Prefer not to say (6)

Other - please specify (7)

Q3 What is your gender?

Male (1)

Female (2)

Non-binary (3)

Transgender (4)

Prefer not to say (5)

Other - please specify (6)

Q4 What is your age? (i.e. 23)

Q5 What year of school are you in?

3rd Year (1)

4th Year (2)

5th Year (3)

6th Year (4)

Other (5)

Q6 What is your major?

Mechanical engineering (1)

Electrical engineering (2)

Biomedical engineering (3)

Computer engineering (4)

Computer science (5)

Industrial design (6)

Prefer not to say (7)

Other (8)

Q7 What is your minor? [if not applicable, respond n/a]

____

Q8 What section of Capstone are you participating in?

▼ ME 4182 A - Wang (1) ... Other (14)

Q9 What is your team's name?

____

Q10 Do you have a sponsored project?

Yes (1)

No (2)

Q11 Have you taken a design class before? (This includes but is not limited to classes like ME 2110, ID courses, etc.)

Yes (1)

No (2)

Q12 Have you taken a sustainability class before?

Yes (1)

No (2)

Q13 Do you have experience with a makerspace or prototyping?

Yes (1)

No (2)

Q14 Is the social impact assessment applicable to your project?

Yes (1)

If no, why? (2) ____

Q16 How important is it to consider social impacts in the design process?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Not important						Very important

Q17 Would you have considered the social impacts in your design project before this course?

Yes (1)

No (2)

Q18 Did you attend the lecture on social impact assessment on October 7th, 2019? [Answer will not impact class standing]

Yes (1)

No (2)

Q19 How helpful was the social impact assessment framework in organizing the steps to perform it?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Not helpful						Very helpful

Q20 How helpful was the framework in terms of overcoming the challenges?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	

Not very much	It helped a lot

Q22 How helpful were the examples provided in the social impact assessment framework?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Not helpful						Very helpful

Q23 How helpful was the social impact assessment framework for organizing your analysis/results?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Not helpful						Very helpful

Q24 What was the most difficult part of the social impact assessment?

Goal and Scope (1)

Inventory Analysis (2)

Impact Assessment (3)

Interpretation of Results (4)

Q25 How much did it help you determine which stakeholders are impacted more?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Not very much						It helped a lot

Q26 How easy was it to identify the challenges/overcome them before using the framework?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	

It was simple		It was difficult

Q27 Please use this space to explain any answers above and to provide additional comments.

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